VOL. XXXIII 1918

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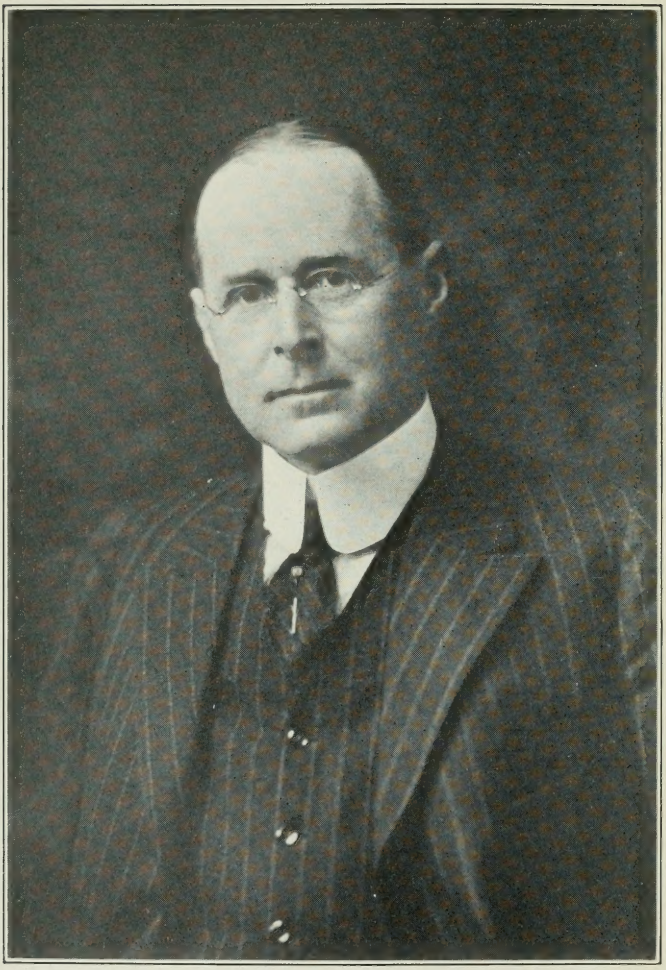

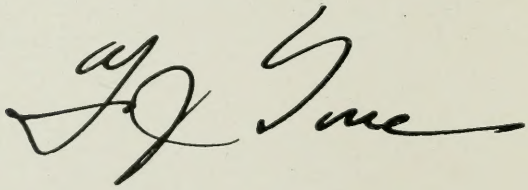

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TRANSACTIONS

OF THE

AMERICAN ELECTROCHEMICAL SOCIETY

VOLUME XXXIII

THIRTY-THIRD GENERAL MEETING

ON A TRIP THROUGH THE APPALACHIAN SOUTH

APRIL 28-MAY 5, 1918

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TRANSACTIONS

OF THE

AMERICAN ELECTROCHEMICAL SOCIETY

PROCEEDINGS

CONDENSED MINUTES AND CURRENT DESCRIPTION OF THE THIRTY-THIRD GENERAL MEETING OF THE SOCIETY, HELD ON A TRIP THROUGH THE APPALACHIAN SOUTH, APRIL 28, 29, 30, MAY 1, 2, 3, 4, 5, 1918.

Number of members participating in the trip, 107; number of guests, 28; total, 135.

The Thirty-third General Meeting took the form of a trip through the principal industrial and power centers of the Appalachian South of the United States, starting from and returning to Washington, D. C. The object in view was particularly to bring Northern and Western members of the Society into close contact with the water power resources and the industrial and mineral advantages of the South, as far as could be accomplished in the time available. The United States Railway Administration, appreciating the present and potential advantages of such a visit, gave permission for the use of a special train for a week, and thus made the trip possible.

The committee of the Society in general charge of the trip was: Chas. F. Roth, Chairman; J. W. Richards, C. G. Fink, Joel H. Watkins and R. P. Hommel.

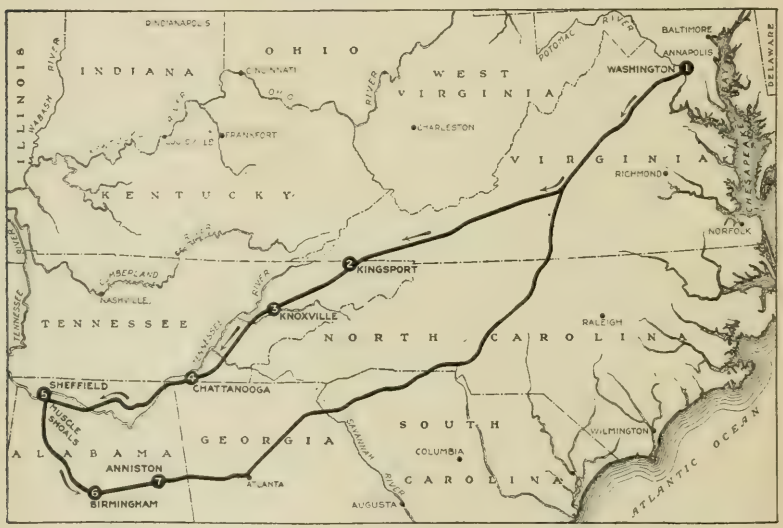
The Committee on Arrangements, to co-ordinate the details of the local events, included Chas. F. Roth, Chairman, W. H. Stone (Baltimore), J. H. Watkins (Washington), V. V. Kelsey (Johnson City and Kingsport), C. A. Benscoter (Knoxville), C. W. Howard (Chattanooga), J. W. Worthington (Sheffield and Muscle Shoals), W. L. Caldwell and Stewart J. Lloyd (Birmingham), and Theodore Swann (Anniston).

Secretary J. W. Richards and Assistant Secretary R. P. Hommel were in direct charge of the train and travelling arrangements.

PROCEEDINGS OF SUNDAY, APRIL 28

Washington, D. C.

Hotel headquarters were at the Raleigh Hotel, Twelfth and Pennsylvania Avenue. Registration began at 12 M., in the English Room Parlor. Members and guests were here provided with badges, assigned places in the train, furnished with programs, lists of participants in the trip, and advance copies of the papers to be read at the meetings *en route*.



Sketch Map of the Southern Trip. (By courtesy of Chemical and Metallurgical Engineering.)

At 4 P. M., Mr. W. Bathon, Washington representative of the McGraw-Hill Publishing Company of New York, conducted a large number of the visitors to the White House, where, by invitation extended through Secretary Tumulty, a private visit was made to the Executive Offices, Cabinet Room, and other interesting features of the building.

At 6 P. M. the special train left the Union Station on the Southern Railway for Johnson City, Tenn. The transportation

for the whole tour was in charge of the Southern Railway, represented by their capable conductor, Mr. C. W. Westbury. The Pullman cars were in charge of Conductor Hardister, and a capable staff of experienced porters. The Pullman Company furnished an all-steel train consisting of baggage car, dining car, three regular sleepers, two stateroom cars, and an observation car—all of the latest type and constituting as fine a train as could be found in America. The participants made themselves thoroughly at home on the train, slept on it each night of the trip, and were thus saved all trouble and expense of hotel accommodation.

At 8.30 P. M. the Board of Directors held a meeting in the Parlor of the Observation Car, ten directors being present in person. The annual reports of the Secretary and Treasurer were received, and incorporated into the Annual Report of the Board of Directors, to be presented to the Society the following day.

PROCEEDINGS OF MONDAY, APRIL 29

Johnson City and Kingsport, Tenn.

Arriving at Johnson City, Tenn., at 8 A. M., the Society became the guests of the Local Chamber of Commerce and was at once ushered in to breakfast at the Hotel Windsor, where a most substantial and characteristically Southern breakfast was served. At its finish, Mr. Lee F. Miller, president of the Chamber of Commerce, greeted the visitors in a well-phrased speech, introducing them to the history, resources and attractions of Johnson City, "Gateway to the Appalachian South," which was suitably responded to by President C. G. Fink.

From 9 to 10 A. M. the members of the Johnson City Chamber of Commerce, together with other residents, took the visitors an automobile ride through and around the city, concluding with a very impressive scene at the magnificent National Soldiers' Home, where the veterans lined up to salute the flag and the visitors, while the band played the Star Spangled Banner.

The train left at 10 A. M. for Kingsport, Tenn.

Arriving at Kingsport at 11 A. M., the party was met at the station by a reception committee, and conducted in automobiles to the Kingsport Inn.

The Local Committee consisted of the following: V. V. Kelsey, Chairman; Byron C. Fowles, E. H. French, D. C. Boy, J. Fred Johnson, J. W. Dobyns, W. M. Bennett, Royal B. Embree, R. Y. Grant, J. C. Stone, W. S. Nicholson, Wm. Roller.

Mrs. J. W. Dobyns, Chairman Ladies' Committee.

Assembling in the parlor of the Kingsport Inn, addresses of welcome were made by V. V. Kelsey and J. Fred Johnson, the latter introducing ex-Governor Cox, of Tennessee. These speeches were responded to by President Fink. Abstracts from these addresses follow:

Governor Cox: "Mr. President, ladies and gentlemen of the American Electrochemical Society: On behalf of this splendid people, it is my happy privilege to welcome you to Kingsport, the magic city of Tennessee. This is an historic section. To the red man it was a land of game, flowing with milk and honey. Here at Pactolas, meaning Flowing Sands, at the head of Long Island, were manufactured the first wrought-iron nails ever manufactured in the South, and they were freighted down the river as far as New Orleans. Here in 1806 there were four powder mills in operation; there were oil mills, tanneries and other manufacturing interests. Here was manufactured the first silk cloth, the first cotton cloth, the first woolen cloth and the first charcoal iron manufactured anywhere in all this section. To this point came King, the great manufacturer and producer of salt, from Saltville, Virginia, and brought and stored in his warehouses his salt and distributed it to this country and sent it to the trade down the river: hence the name Kingsport. If you were to take a giant compass, and place one prong on Kingsport and extend the other so as to reach out for one hundred miles and swing it round, encircling upper east Tennessee, eastern Kentucky, southwestern Virginia and western North Carolina, you would encompass a territory as rich in minerals and other natural resources as any like section on this globe. Here vast and varied raw materials are to be found, in close proximity—iron, coke, coal, manganese, marble, shale, limestone, zinc and lead—that can be easily and quickly assembled over a short haul down grade. You can load a car with these raw materials on the Carolina, Clinchfield and Ohio Railroad,

80 miles north of Kingsport or 100 miles south, and turn it loose and it will drift into Kingsport without motive power. (Applause.). In enumerating the advantages of Kingsport, I have left out its greatest asset, its captains of industry. These gentlemen need no word of commendation at my hands. Gentlemen, we know that we have a country as rich in natural resources as any country in the world, and we feel sure that if we can get you to come into our midst and apply your knowledge, your skill, your energy to the development of this country, that it will be the greatest country upon which the sun shines. Here at Kingsport and in this section is as fine water power as can be found in the Appalachian Range. We must look to you to match the German chemists. Ah! to over-match the German chemists, and to give to our brave boys and their comrades in arms, the Allies, the ordnance and the munitions with which they are to make the world safe for democracy and guarantee it a peace for all the future. (Applause.) Gentlemen of the American Electrochemical Society, I welcome you, thrice welcome you, to hospitable Kingsport and to fair Tennessee, the Empire State of the South." (Applause.)

President Fink: "Governor Cox, representatives of Kingsport, fellow members: It is difficult to find adequate words in expressing the Society's appreciation for the warm welcome that we have been accorded here in Kingsport. It was not until about seven years ago that the Carolina, Clinchfield and Ohio Railroad discovered Kingsport, and in that short time the population of Kingsport has increased almost a thousand per cent. The C., C. & O. R. R., contrary to the custom of other railroads in this country, resorted to a method which seems rather strange from a railroad man's point of view: It went to the geologist and to the chemist, and asked them for advice as to how to proceed to build up the country. Other roads, the Pennsylvania for example, have had chemists in their shops analyzing steels and oils, but the Carolina, Clinchfield & Ohio engaged a consulting chemist, a chemist who knew what chemical industries were. A chemist alone could never have built Kingsport, but a chemist with the backing and support of a generous, far-sighted railroad company

has built up one of the most wonderful chemical centers here in the South. Too much credit cannot be bestowed upon the railroad company."

The writing-room of the Kingsport Inn and the front portico were converted temporarily into a mineralogical museum, where were displayed a fine collection of the ores, minerals and building stones of the immediate vicinity and of the Kingsport district along the line of the Carolina, Clinchfield and Ohio Railway, which passes through Kingsport. Among the notable exhibits were the famous Cranberry iron ore (the purest in the United States), feldspar, dolomite, kaolin, manganese oxide (now being mined and shipped to Anniston, Alabama), quartz, limestone, mica, zinc blende, calamine, soapstone, asbestos, chromite, fireclay, talc, ocher, bauxite, salt, pyrites, graphite, phosphate rock, gypsum, barytes, corundum and cassiterite (tin stone). Mining Engineer Kemsil gave a great deal of time to enlightening visitors concerning the occurrence and mining of these minerals in the Kingsport region. These abundant mineral resources, together with cheap coal and considerable water power, have made Kingsport the most rapidly advancing chemical manufacturing center of the South, and lend great interest to the various manufacturing plants and chemical industries which have recently been started there.

At the conclusion of the addresses, automobiles were at hand to take the guests a few miles outside the city to Rotherwood Farm, where at the beautiful Colonial home of Mr. and Mrs. J. W. Dobyns, at the confluence of the North and South Forks of the Holston River, lunch was served on the terrace and porch by the ladies of Kingsport. This historic house, built in 1776, and surrounded by a model farm, was an interesting type of a Southern home in the blue-grass pasture region. The lunch and its setting formed a most unique and picturesque occasion long to be remembered by everyone who was there.

Returning to Kingsport after lunch, the inspection of the various plants there was taken up in the following order:

Kingsport Extract Corporation, manufacturers of liquid and powdered tannin extract.

Kingsport Tannery, Inc., capacity 125 hides daily.

Kingsport Pulp Corporation, standard soda wood pulp.

Kingsport Hosiery Mills, makers of standard hosiery.

Clinchfield Portland Cement Corporation, operating lime kilns on the R. K. Meade system, condensation of dust by the Cottrell Electrical Precipitation Process for potash recovery, rotary coal-dust-fired cement kilns, and independent electric power plant.

Kingsport Brick Corporation, manufacturers of Velvetone brick, rug texture bricks, building tile, paving blocks, sewer pipe and agricultural tile, made from the ferruginous shale of a hill adjacent to the works.

The Federal Dyestuff and Chemical Co., makers of dyes, chlorine products, picric acid, tri-nitro toluol, etc. The electrolytic chlorine plant at this works is on the Allen system. The capacity of this plant for manufacturing explosives was found only partly operated, and representations were made that the Government was not utilizing its facilities to the fullest possible extent. Acting on these representations and their own observations, the Board of Directors of the Society took action later in the form of a recommendation to the Government that the manufacturing capacity of this plant be investigated; the resolutions adopted and the answer of the Government thereto may be found in the proceedings of the Board of Directors, page 44 of this volume.

After the visits to plants, a representative of the Carolina, Clinchfield and Ohio R. R. exhibited in the local moving-picture theatre motion pictures showing the country traversed by that railway, its mineral, water power and industrial resources. Pamphlets were also distributed, giving details of the mineral resources; copies may be obtained by addressing D. C. Boy, Acting Industrial Agent, C., C. & O. R. R., Johnson City, Tenn.

A complimentary dinner was given the Society, as guests of the Local Committee, in the Kingsport Inn, at 6.30 P. M. An orchestra furnished stirring patriotic music. About 150 participated. At its conclusion, the annual business meeting of the Society was called to order by President Fink, at 8.30 P. M.

Secretary Richards read an abstract of the annual report of the Board of Directors to the Society, accompanied by the annual

report of the Secretary and the Treasurer. These reports were accepted and are appended to the Proceedings of this meeting. This was followed by the announcement of the election of new officers of the Society, and other items of business, which are also printed in detail at the end of these Proceedings. At the conclusion of the business meeting, Dr. Carl Hering rose to remark that he had attended all the meetings of the Society except two, and thought he could say authoritatively that the present meeting promised to be one of the most interesting, if not the most interesting, of them all, and he therefore took pleasure in offering the following resolution, which was passed unanimously:

"The American Electrochemical Society wishes to put on record its great appreciation of the true Southern hospitality and of the enthusiastic reception given its visiting members and guests at Johnson City by the Board of Commerce, and at Kingsport by the efficient Local Committee; by the industrial plants which opened their doors to our visits, and by the gentlemen and ladies of the two cities who co-operated in various ways to make this day a memorable one in the history of the American Electrochemical Society."

PRESIDENT FINK: "Since our last meeting at Pittsburgh, we have lost one of our dearest members, a member who was one of the three founders of our Society, Dr. Eugene F. Roeber. Dr. Roeber put his whole heart and soul into the Society, and much of its success is due to his untiring efforts. Dr. Roeber was likewise one of the originators of that splendid journal, Metallurgical and Chemical Engineering, whose pages he edited in a masterful manner. Only those who knew Dr. Roeber and knew him well can appreciate how much we miss him. In deference to his memory, I request you all to rise."

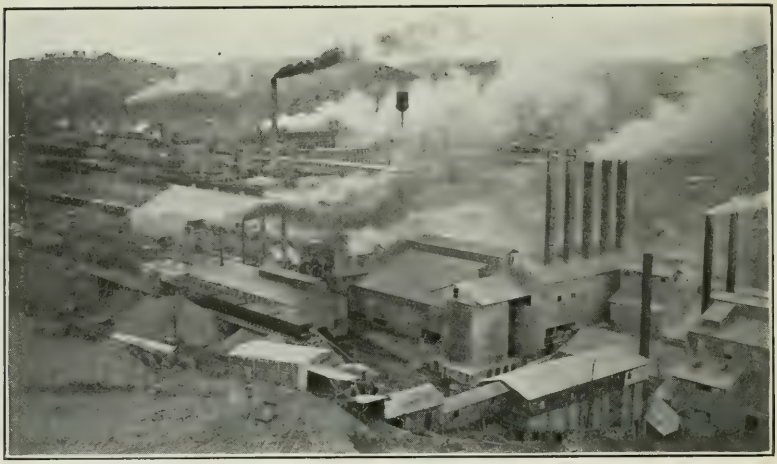
After the business session, speeches were made by V. V. Kelsey and C. F. Roth, and responded to by President-elect F. J. Tone, as follows:

F. J. TONE: "Mr. President and fellow members of the Society: I thank you more than I can say for the honor of being called to serve as your President for the ensuing year. It is one of the real honors that can come to an electrochemist, because it carries

Johnson City, Tenn.—Industrial Section.

National Soldiers' Home, Johnson City, Tenn.

Kingsport, Tenn.—General View.



Kingsport, Tenn.—Industrial Section.

Lunch at Rotherwood Farm, Kingsport, Tenn.

with it the opportunity to serve, the opportunity for accomplishment, and while I appreciate the honor I am more deeply sensible of the responsibilities which the office carries. We have a great work before us. The entire electrochemical energies of this country must be devoted to the winning of the war. This is our work. Then we shall have to consider soon the great problems of reconstruction after the war, and it will need the united wisdom of our entire Society to solve these problems aright. I am sure I can count on the co-operation of every member in seeing that we measure up to our great opportunity, and for my part I wish to pledge my full energies for the accomplishment of this result."

Mr. Tone concluded his remarks by voicing the deep appreciation of the Society for the splendid hospitality of the people of Kingsport and the great interest and profit which the members had found in their first day's study of the resources of the South.

The evening proceedings adjourned at 9.30 P. M., after which most of the party went by automobiles to the Federal Club, where dancing was indulged in until train leaving time, 12 P. M. A large table at the Federal Club contained a fine exhibit of dyes and dyed materials, picric acid and T.N.T. made by the Federal Dyestuff and Chemical Co.

Thus ended a most strenuous but equally interesting and profitable day.

PROCEEDINGS OF TUESDAY, APRIL 30

Knoxville and the Knoxville District

The train arrived at Mascot, ten miles from Knoxville, at 6.30 A. M., where the party was first conducted to breakfast in the workmen's dance hall of the American Zinc, Lead and Smelting Co., as guests of the company. After breakfast, and a brief interchange of complimentary remarks, the guests were conducted in small parties through the extensive concentrating mill, where 1,000 tons per day of zinc sulphide ore is treated. The treatment consists of high-speed crushing, jigging, concentrating on tables, use of Dorr thickeners, and final concentration by oil flotation. The ore is zinc blende in limestone, similar to the Oklahoma-Miami District ore. The operations were very interesting to the visitors, who were thus able to see one of the largest and most

modern ore-concentrating mills in America in full operation; the oil flotation plant attracted particular interest. The mill is run entirely by electric power, transmitted from the Tennessee Power Company's plant at Ocoee Dam.

Returning to the train, Knoxville was reached at 9 A. M. Here the party was met at the station by the Local Committee, consisting of the following, and numerous other local engineers and ladies:

C. A. Benscoter, Chairman; W. W. Bonham, W. M. Fulton, H. B. Lindsay, R. L. Foust, Oscar Handley, R. S. Hazen.

After exchange of greetings, a special train of four coaches standing on an adjoining track was boarded, and the party left for Alcoa and Cheoah, via Maryville. The train was provided by the Knoxville Board of Commerce, and the Aluminum Com-Company of America were hosts at the luncheon provided at Alcoa. Passing Maryville, where is situated a large reduction plant of the Aluminum Company of America, the train passed along the Little Tennessee River into the Great Smoky Mountains, up to the site of the great dam built at Cheoah. At this spot an arched dam 234 feet high, with overflow over the crest, is being built, with power house at its foot. Three such dams and nine auxiliary dams are expected to afford 300,000 kilowatts. For detailed description see paper in this volume by Prof. J. A. Switzer.

After inspection of the half-completed power house and the partly completed dam, the party returned to Alcoa, where they were the guests of the Aluminum Company of America at lunch, in the station building. A 4 P. M. the train returned to Knoxville, every visitor greatly impressed by the size and importance of the enormous water power project, and with the enterprise and foresight of the Aluminum Company of America.

Taking automobiles from the station, after a drive through the residential section of Knoxville, the party foregathered in the assembly room of Science Hall at the University of Tennessee, for the purpose of holding a business session. The hall was decorated with flowers and flags, and formed an ideal place for a scientific meeting.

Mayor MacMillan welcomed the visitors to Knoxville, and briefly sketched its history and characteristics.

Guests of the Aluminum Co. of America, at Alcoa, Tenn.

GROUP OF DIRECTORS OF THE SOCIETY AT ALCOA, TENN.

From left to right: L. D. Vorce, J. V. N. Dorr, C. G. Schluederberg, F. J. Tone, (C. F. Roth), C. G. Fink, A. T. Hinckley, H. C. Parmelee, P. G. Salom, J. W. Richards, Carl Hering.

President Dr. Brown Ayres, of the University of Tennessee, welcomed the Society to the collegiate campus and historic halls of the University, as follows:

Brown Ayres: "Mr. Chairman and Gentlemen of the Society: The University of Tennessee is the oldest public institution west of the Allegheny Mountains. It has served its State long and faithfully. It has sent out some men of great distinction. I will not try to give you any long list of them, but two names of men prominent in public life at the present time that we claim as our graduates as well as our alumni are well known to you, Mr. William G. McAdoo, the Secretary of the Treasury, and Hon. Philander P. Claxton, the Commissioner of Education of the United States. This is the land grant college of Tennessee; it is the college that receives from the Government the funds for the encouragement of agriculture and the mechanic arts under the Morrell Act. As such, the tone of the institution is perhaps predominantly scientific, although we do not, by any means, neglect the classical and cultural side of things. Being scientific, you can understand, therefore, that I speak with the utmost sincerity as the representative of the faculty when I say that we are delighted to welcome here a scientific body like this American Electrochemical Society, and being a scientific man myself, an electrician and something of a chemist, I can express my personal pleasure and gratification at having this Society with us. We are old in a sense, but we are young in vigor and in determination and a desire to serve our State and our Nation, and we know that in no way can this be done better than by standing beside the men who are trying to build up and bring forward the natural resources of this State, which are so many and so varied. The University feels that it has great opportunity and duty, and its highest pleasure will be to co-operate in the upbuilding of this beautiful Appalachian Valley, than which, I think, there is no fairer spot in this great land of ours. We know that you have come here for business. We are anxious to hear the learned papers that you have to present, so that I will not detain you longer with any speech other than to repeat again that, from the bottom of our hearts, you are welcome." (Applause.)

President Fink responded for the Society.

Papers were then presented and discussed as follows: L. Simpson (presented by C. A. Winder), C. W. Hazelett (presented by P. G. Salom), W. D. Bancroft (presented by Carl Hering), P. H. Brace (presented by E. C. Sullivan), H. M. Ryder (presented by J. W. Richards), and an informal talk on "Nitrogen Fixation Furnaces" by E. Kilburn Scott. The papers and discussions are printed in full in this volume of Transactions; Mr. Scott's communication is held over as a contribution to the next volume.

At the close of the discussion the meeting adjourned, and automobiles were taken for a pleasure drive through the city and its environs, including the agricultural experiment farm of the University of Tennessee.

While the gentlemen were at their scientific session, the fifteen ladies of the party were entertained at tea by the Knoxville Women's Reception Committee, Mrs. S. G. Shields, Chairman, at the home of Mrs. Charles Wait, and Tennessee pearl pins were presented to the ladies as souvenirs.

At 7.30 P. M. the visitors, with the Local Committee and many prominent citizens of Knoxville, gathered at the Cherokee Country Club, overlooking a wonderful horse-shoe bend of the Tennessee River. Here we were guests of the Knoxville Board of Commerce, at a banquet enlivened by plantation melody singing and other forms of entertainment. A beautifully illustrated program, including the banquet menu and proceedings of the evening, was distributed. Hugh M. Tate, Esq., of Knoxville, was a most efficient and eloquent toastmaster, and greeted the assembly with a most eloquent speech.

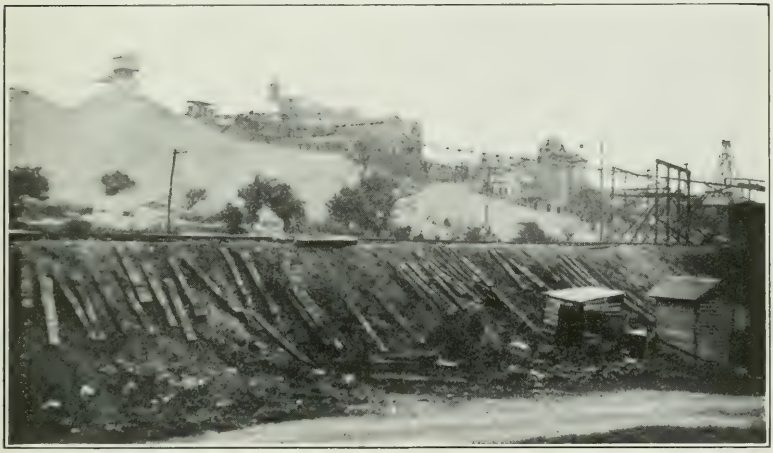
Dr. Colin G. Fink, retiring president of the Society, then delivered his Presidential Address, on "Electrochemistry and National Economy," which will be found printed in full in this volume of Transactions.

Mr. C. G. Schluederberg, Chairman of the Society's Membership Committee, spoke upon "The Part United States Industries Must Perform to Enable the Allies to Win the War," which will be found printed in full in these Transactions.

Dr. Yogoro Kato, of Tokyo,[1] one of the visitors, being called

[1] Director of the Nakamura Institute for Chemical Research, and Professor of Electrochemistry in the Tokyo Technological Institute. Graduate of the Massachusetts Institute of Technology.

Clinchfield Portland Cement Corporation Plant, Kingsport, Tenn.



Concentrating Mill, American Zinc Co., Mascot, Tenn.

Building a New River Bed, Mascot, Tenn.

View of Tennessee River from Cherokee Country Club, Knoxville, Tenn.

Science Hall, University of Tenn.

Negro Laborers' Camps, Cheoah, N. C.

Dam Under Construction at Cheoah, N. C.

on to speak for the ten Japanese in the party, made some very friendly and timely remarks, in part as follows:

Dr. Kato: "Ten years ago I was in Boston, and at that time many of your countrymen were speaking about the need of having a research laboratory for a chemical industry, the outcome of which was that you have the Bureau of Standards, the Mellon Institute, the research laboratory connected with the General Electric Company, etc. We, in Japan, are just thinking of having similar research laboratories, and we think about this seriously. We have begun to have research laboratories in Japan, and we hope that some time, maybe fifteen years later, that we may have as a result as many wonderful chemical industries as you have in this country. We wish to co-operate, as our government is doing, in one way or another, and I wish to ask you to help us in making advancement in science and industry. I am very anxious to tell you about the present condition of our electrochemical industry in Japan, but I am sorry that my command of the English is so poor. I am very glad, however, that I was invited to speak and I thank you very much for your attention." (Applause.)

The final feature of the evening was an address by Professor J. A. Switzer, of the University of Tennessee, on "The Undeveloped Water Powers of Tennessee." The address was given in abstract, accompanied by lantern-slide pictures of water power plants, and of the party visiting the Cheoah Dam that same afternoon. The address is printed in full in this volume of Transactions.

The session was closed by Mr. Tone, President-elect of the Society, who thanked the Knoxville Chamber of Commerce and the people of Knoxville for their unbounded hospitality and for the exceptional opportunity they had afforded the members to study the great natural possibilities of the region for the development of electrochemical industries.

Automobiles then carried the party to the station in Knoxville, whence the special train left at 12 P. M. for Chattanooga.

PROCEEDINGS OF WEDNESDAY, MAY 1

Chattanooga and Vicinity

Arriving at 6 A. M., breakfast was scheduled at the Hotel Patten at 7 A. M. Here the party was met by the Local Committee, constituted as follows: C. W. Howard, Chairman; Bruce Crabtree, Emmett Rogers, Paul J. Kruesi, George L. Davison.

Mr. Howard made an address of welcome to the visitors in the parlor of the hotel.

After breakfast, accompanied in automobiles by our Chattanooga hosts, the following round of visits was indulged in:

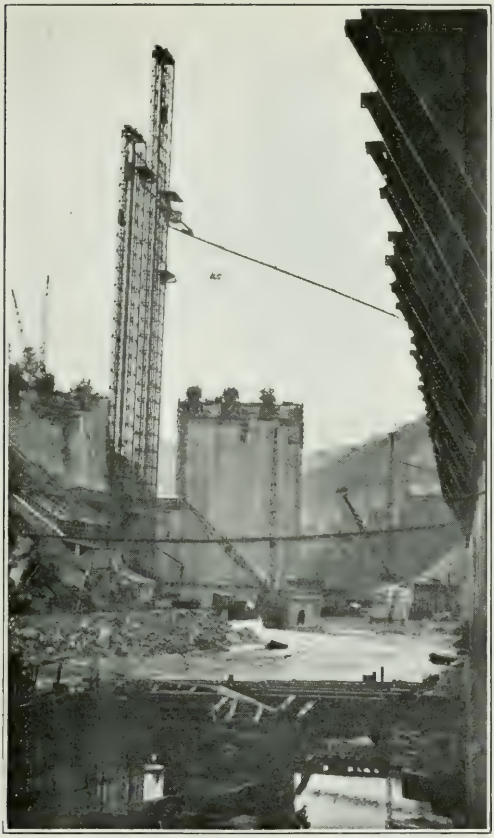
Inspection of Southern Ferro-Alloys Company's 2,500-horsepower plant, where several electric ferro-silicon furnaces were seen in full operation. The Semet-Solvay By-Product Coke and Toluol Plant. Wilson and Company's Cottonseed and Peanut Oil Refinery, for hydrogenation of oils to fats, where were seen the refining of oils and the electrolytic hydrogen plant.

Passing through the historic Chickamauga Battlefield, the Crystal Spring's Bleachery was visited, offering a good view of a model Southern cotton mill, with all its appurtenances.

Returning through the Chickamauga Battlefield, the visitors were taken to the heights overlooking Chattanooga, and thence descended to the city and assembled at the Manufacturers' Association Building, where samples of the products of 125 of the leading Chattanooga industries are on exhibition.

Leaving there at 12.30 P. M., a half-hour run in automobiles brought the party to the boat landing on the Tennessee River, where the steamer "J. N. Trigg," engaged by the Chattanooga Industrial Board, commanded by Capt. Conway Graydon, and well-provisioned withal, was waiting for the twenty-mile trip down the river to Hale's Bar. *En route* an enjoyable box lunch was served, and the river scenery was greatly enjoyed.

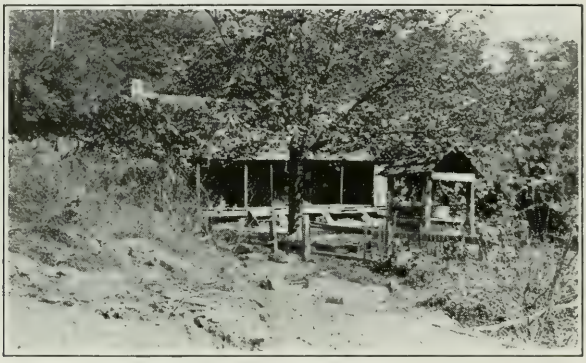
Arriving at Hale's Bar at 3.30 P. M., an hour was given to the inspection of the great dam and power house, on which $11,000,000 is said to have been expended, with 45,000 horsepower now in operation and 50,000 more projected in a new power house. The difficulties met with in building the dam, the leakages through cracks in the limestone, the troubles caused by high water (the flood water flow amounts to nearly twice the normal flow of the



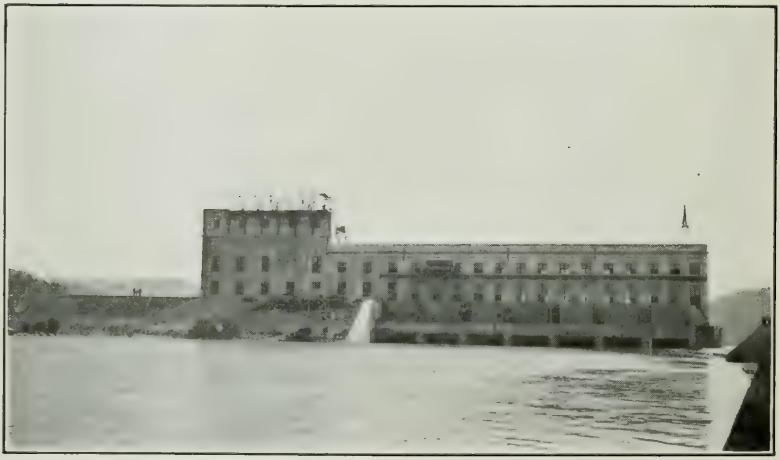
Dam at Cheoah, N. C., under construction.

At Hales Bar, on the Tennessee River.

Diversions on Board the Steamer Trigg, on the Tennessee River.
(Ducking into flour for coins.)



Squatter's Cottage, at Hales Bar.



Hales Bar Power House, Tennessee Power Co.

Niagara River) were some of the topics discussed at length. The enormous oil switches, and high-tension transformers, and other details of the power house excited the admiration of the visitors.

Returning to the steamer, the return trip was made to the boat landing by evening light, where electric cars were taken for Signal Mountain. Arriving on the summit just at dusk, all were ready to sit down appreciatively to a bounteous banquet in the Signal Mountain Inn, attended also by a large number of the business men of Chattanooga, and their wives. After coffee, ex-Mayor T. C. Thompson called upon the Hon. H. C. Evans, ex-Consul General of the United States at London, who welcomed the visitors; Mr. E. M. Jones talked upon the coal and iron resources of the Chattanooga District; ex-Senator Newell Sanders spoke; Colonel Bogard, "Father of the Hale's Bar Lock and Dam," was called on, and Doctor Paul Maynard delivered a paper on the Electrochemical and Metallurgical Resources of the Chattanooga District. Dr. C. G. Fink replied for the Society, and Mr. E. Kilburn Scott made remarks in behalf of "Our Allies."

The addresses of Mr. Jones and Mr. Maynard are printed in full in these Transactions.

At 10.30 P. M. the banquet was ended, and electric cars taken for the city, arriving at the station at 11.30, whence the special train departed for Sheffield, Alabama, at 11.45 P. M.

PROCEEDINGS OF THURSDAY, MAY 2

Sheffield, Alabama, and Muscle Shoals

Arriving at 7 A. M. the following reception committee met the party at the Sheffield Hotel, the visitors being guests of the Local Committee, of which Mr. W. G. Waldo was the efficient chairman. Handsome engraved programs of the day's activities were distributed.

The Entertainment Committee of Florence, Sheffield and Tuscumbia consisted of the following: W. G. Waldo, chairman; W. H. Mitchell, C. W. Ashcraft, J. W. Worthington, G. E. Roulhac, J. T. Kirk, John Johnson.

After breakfast Col. Worthington briefly addressed the party, welcoming them to Sheffield, Florence, Tuscumbia and Muscle

Shoals, and predicting that the nation as a whole would benefit by the development of the resources of the Southern States, but that particularly the electrochemical industry would benefit from the development of Southern water powers. President Fink replied.

Automobiles to the number of about forty, driven by local residents, then formed in procession, and passing through the flag-bedecked streets of Sheffield and between rows of school children waving flags and cheering, made their way first to plant number one, which is being built to work on the synthetic process of ammonia nitrate manufacture developed by the General Chemical Company. Capt. R. W. Hemphill, in charge for the Government, and Messrs. J. G. Munson and J. G. Oliver for the contractors, accompanied the party. Arriving at the works, which was in process of construction and about two-thirds built, Capt. Hemphill addressed the assembled visitors as follows:

Capt. R. W. Hemphill: "The very pleasant duty has been assigned to me of welcoming you, one and all, to Sheffield, and to Nitrate Plant No. 1. This plant is being constructed under appropriations made some two years ago of $20,000,000 for the production of ammonium nitrate in this country. The General Chemical Company offered to the Federal Government the use of their process known as the synthetic process for the production of ammonia. They very generously and patriotically offered its use during the period of the war to the Federal Government. This plant was located here on September 10, 1917. The Committee on Selection of Site arrived in Sheffield and looked over this site and other sites in this vicinity. On the first of last October orders were issued to the officers of the Ordnance Department to come to Sheffield and inaugurate the construction of this plant. On October 2d the contract for the construction of this plant was signed by the J. G. White Engineering Corporation, and the general construction of the plant has been in their hands since that period. On October 23d the first carload of material arrived, and since then the work has gone on in strictly orthodox manner. There have been no strikes, there have been no holdups, there has been no suspension of operations, and no work of this character that I know of has gone on with less friction and a

more harmonious working of all the factors. The large building in front of you is the process building, 240 by 225 feet (72 x 67 m.). The power house is directly before you, 5,000-horsepower boilers, 4,000 kw. capacity; two large stacks of 200 feet (60 m.) each. On the hill here is the concentration, the oxidation, and, further over, the absorption plants. They are going along under a contract awarded to the General Construction Company. The work there is progressing in a very satisfactory manner, and then, further on beyond, are the two nitrating houses. Other features of the work have not been outlined because not authorized at the present time; I may speak of them as other processes in an experimental way; and further over, on the outskirts, we have a large experimental laboratory that is carrying on work of a very interesting nature. We also have under consideration the establishment of large coke-oven processes. The auxiliary features of the work are the hospital, which we have at the right; we will pass presently the commissary buildings, the negro camp, the white camp, the cottages for the married workmen and foremen; you will all have an opportunity to see them, I presume, before you leave."

The party then proceeded to Tuscumbia, where the cottage home of Helen Keller was pointed out, and the great Government Spring visited, flowing 28 million gallons daily. Here again we were greeted by cheering school children.

At 10 A. M. the procession of automobiles traversed the busy streets of the cantonment built for laborers at the Nitrate Plant No. 2, where 12,000 workmen are housed. Proceeding to the moving picture theater, addresses were delivered by Capt. J. W. Young, representative of the Air-Nitrates Corporation, and Mr. E. J. Pranke, manager of the Service Bureau of the American Cyanamid Co.; the latter accompanied by moving pictures showing various stages of construction of the plant. The addresses are abstracted as follows:

Captain J. W. Young: "Ladies and gentlemen of the American Electrochemical Society: We feel it is a great privilege to welcome you to this plant. We welcome you as American citizens, anxious to see what is being done to give to the soldiers on the other side their proper ammunition; and we welcome you as the

American Electrochemical Society, because from your experience and training you can appreciate so fully what we are trying to do. This plant is being constructed by the Air-Nitrates Corporation as agent of the U. S. Government, under the supervision of the Ordnance Department of the army. There are, as sub-contractors here, Westinghouse, Church, Kerr & Company, the J. G. White Engineering Corporation and the Chemical Construction Company for the larger work, and other contractors for special parts of the job. The plant work was begun here on December 20th, 1917, when the first carload of material arrived. Since that time the progress has been continuous. At the present time we have on our payroll 13,000 employees working on the plant. Every provision is made to take care of the health of the men and to give them proper recreation. I am going to ask Mr. Pranke to give you a general outline of the process and the location of the buildings."

Mr. E. J. Pranke: "The plant is laid out so that materials are received at one end and the product leaves at the other. About a million tons of raw materials is used at this plant in a year, and a hundred thousand tons of ammonia nitrate produced. The daily production of ammonia in the form of NH_3 is 150 tons. About three hundred and fifty thousand tons a year of limestone will be burned. We believe that this is the largest lime plant in the United States and perhaps the largest in the world. To one side of the lime plant is a coke-drying plant in which will be dried over one hundred thousand tons of coke per annum. The lime and coke are mixed and combined by fusing with an electric current in carbide furnaces. These carbide furnaces, we believe, are equal to or greater in capacity than the entire carbide production of the United States and Canada. From the carbide furnaces the carbide goes to the cooling sheds. After it is cooled it is ground to a fine powder and placed in ovens holding about a ton each of the powdered carbide. To the right we have a liquid air plant which, we believe, produces more liquid air than all other liquid air installations in the United States and Canada. Liquid air is produced, as you know, by pressure combined with cooling. The nitrogen produced here is of extreme purity. It is piped to the lime nitrogen room, where it combines at a white

heat with the powdered carbide. The product here will contain about 25 percent of ammonia, or 21 percent of nitrogen. The cans of lime nitrogen are removed and cooled and again ground to a powder which is passed on to a hydrating plant and then to the autoclaves. There is adjacent to the autoclaves a power plant; you may see the size of it as you go out; it furnishes the steam for the autoclaves. The autoclaving of cyanamid is a well-known process. It was described by Dr. W. S. Landis at a meeting of the American Institute of Chemical Engineers in Baltimore about January, 1916. That paper can be referred to in the chemical literature. The ammonia next goes to the catalyzing rooms, where it is mixed with air and pressed through a platinum screen which is maintained at a red heat by an electric current. The nitric oxide and steam and oxygen, and of course some nitrogen from the air, go to the cooling towers and thence to the nitric acid absorption towers. The nitric acid is made from about one-half of the ammonia produced in the autoclaves. That nitric acid then, with the remaining half of the ammonia produced, is combined in the neutralizers. The nitric acid and ammonia form ammonium nitrate. There are five ammonia nitrate houses, separated as you see, for purposes of safety. A part of the power for the plant is to be produced on the grounds, about forty-five thousand kilowatts, by steam, and the remaining requirements about thirty thousand kilowatts, will be obtained from existing hydro-electric plants in this vicinity.

"Every step in this process has been carried out on a commercial scale for varying lengths of time. Cyanamid, as you know, has been made at Niagara Falls since December, 1909; considerable improvements have been made in the process; the percentage of fixed ammonia in the original product was about 18½ percent. That has been increased in regular practice to about 25 percent. The autoclaving of cyanamid has been carried on in regular commercial operation for about three years in three or four commercial plants in different parts of the United States. The oxidation of ammonia has been carried out continuously for about a year and a half in the same sized equipment as is used at this plant. The use of cyanamid ammonia with nitric acid has been continuous for about three years in regular commercial operation. Every piece of equipment here is the standard commercial article.

There is no reason why the plant that is being constructed out here should not proceed smoothly from the day that operations begin. The only difference between this plant and previous plants that have been constructed utilizing this process is that there are merely more units hooked up one after the other here, but there is no difference in the nature or size of those units."

Returning to the automobiles, a tour was made of the plant, under the direction of Capt. S. L. Coles representing the Government, Mr. J. W. Young the Air Nitrates Corporation, and G. W. Burpee, M. T. Thompson and T. C. Oliver the contractors.

The process to be used is the Cyanamid Process of Ammonium Nitrate Manufacture, developed by the American Cyanamid Company and under the supervision of the Air Nitrates Corporation, Henry G. Washburn president, and Walter S. Landis chief technologist. The huge plant was seen about half completed, the automobiles taking the visitors in and out between the various buildings, giving a vivid idea of the magnitude of the plant and the haste with which it is being constructed.

Leaving Plant No. 2, the Tennessee River was crossed by a double-deck steel bridge to the town of Florence, on the north bank, the headquarters of the U. S. Engineer Corps in charge of construction of the great dam across the river, which is estimated to cost $16,000,000. Col. H. L. Cooper is the U. S. Dist. Engineer Officer in charge. The streets were decked with flags, and the school children assembled at the post office gave a rousing welcome to the procession as it passed. The automobile ride was continued eight miles up the river to Lock Six on the Muscle Shoals Canal, where, on the grassy bank, shaded by huge trees, a barbecue luncheon was served by the ladies of the communities visited. The scene was highly picturesque and enjoyable.

Under the amphitheater of trees, backed by the wide river, a platform had been erected and large screens in which were displayed maps and diagrams showing the resources of the Muscle Shoals region. The Tennessee River Improvement Association, the hosts, distributed to each one present, through Col. Worthington, a handsome morocco-bound souvenir volume, containing complete unabridged information concerning the water power possibilities at Muscle Shoals, and the arguments for the establishment

there of the National nitrate plants. This handsome gift was highly appreciated. The complete project proposes the building of two large dams across the Tennessee River, each about one mile long and one hundred feet high, intended to develop a maximum of 660,000 horsepower, only part of which will be absorbed by the Government nitrate plants, leaving some 500,000 horsepower for sale to other industries. Work has not progressed further than drilling for rock foundations on the proposed sites of the dams.

After luncheon, speeches were made as follows:

Mr. W. G. Waldo: "There is little I can add on behalf of our local people in greeting the members of this Society. I am able, however, to bring to the attention of the members of this Society something of the magnitude of this great undertaking and its far-reaching importance in the welfare of the Nation, both now and in the future. The facts are set forth in a souvenir book which was prepared for the occasion of the coming of the Inter-Departmental Nitrate Board comprising the Secretary of War, the Secretary of the Interior and the Secretary of Agriculture, who visited this section of the country to inspect this location for a Government nitrate plant.

"We had planned to have a special souvenir prepared for this occasion, but unfortunately we were unable to execute our plans in time. Instead of the souvenir which we should have had we are therefore substituting "America's Gibraltar—Muscle Shoals." The drivers of the cars will please come forward now and distribute these books among the guests and see that each guest gets a book."

Col. Worthington: "We are so pleased with you that we want to tell you again, in simple words, how we appreciate your coming. There is significance in your visit, and that significance is not local. No country can fight an offensive or defensive war without the electrochemists, and the part that you have played and that other chemists in other nations have played in this war, is perhaps the most important part. We here have long striven to get assistance, to get co-operation, to partly do in the South what has been done at Niagara Falls. As far back as 1899 Niagara Falls was an experiment, but today it is the center of

the electrochemical industry of the world. Here, too, we would like to establish a center and we will know how much the development depends upon you, because, among the other things that this country is suffering from, it is suffering from a want of appreciation and a knowledge of the electrochemical industry. (Applause.) At Niagara Falls is to be found the location where there is the most expensive waste in the world, because the dam was built by Nature. Scenic beauty at Niagara Falls is costing forty to fifty million dollars annually, and while we may have scenic statesmen at Washington in Congress, I believe you will agree with me there are no electrochemists. I heard Dr. Baekeland say one day that if there were ten engineers in Congress we would save five hundred million dollars a year, and I believe it. (Applause.) But, gentlemen, don't grow ambitious; there is not much danger of your tribe ever going there. (Laughter.) Don't let me discourage you, however. I hope in time that this country will have enough sense, enough scientific sense and enough common sense, to send some of you there. (Applause.)

"Go back with me, please, to the time when, in the seventies, the first intimation came from New England that the war of the States was over. The Puritans invited the Cavalier, the matchless Henry Grady, to take dinner with them, and there at that dinner, among other things, he said, like a wail from a wilderness, "Come down and help build up the waste places that New England, the North and the South have wrought." He meant the waste of war. And now today, as we thank you, appreciate you as American citizens, distinguished as you are in your profession, we appeal to you to come down in this Southern country and stop the electrochemical waste which you see before you. I thank you." (Applause.)

President Fink: "Ladies and Gentleman: Long before the American Electrochemical Society started out on its Southern trip most of its members had heard about the wonderful development that was going on at Muscle Shoals, at Sheffield and at Florence. But I can say with conviction, and the conviction of every member of the Society, that not a single one of us dreamed that there was anything as grand and as magnificent as the development we see here today. (Applause.) There are, among us,

a number of electrochemical engineers from the North who thought that possibly some day Muscle Shoals might, in some measure, compete with Niagara Falls. They merely thought so when they started out on our trip; but now they are convinced."

MR. WINDER: "The optimism that is sweeping the country on water power is indeed wonderful. It has long been the idea that water power was without question a gold mine, and that all the capitalists had to do was to obtain an option upon the property containing the riparian rights and proceed to extract gold from our rivers. It is not impossible that this idea was promulgated by the politician—the self-styled "protector of the people's rights." From time to time capitalists themselves have been deluded with the same idea, and they, in turn, have invested untold millions in water powers which they thought would yield enormous returns on the investments, only to awaken to the proper realization of the situation after it was too late.

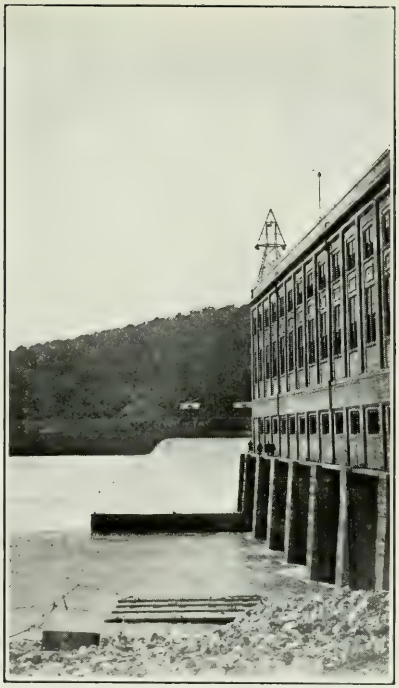
"There is no question but that this optimism is a fine and wonderful thing, particularly at a time when we demand enormous quantities of power for the Electrochemical Industry, and that demand cannot be supplied from the coal and steam plants because, first, of the shortage of coal, and, second, the shortage of steam generating equipment. That this optimism has reached an enormous magnitude is shown by the demands from all parts of the country upon Congress to pass some comprehensive legislation upon water power throughout the entire country.

"At the same time, however, we must not overlook the fact that there will be many things in the way of development even after we have the legislation spoken of. This legislation is not an 'open sesame' to wealth; it is far from it, unless such water power should be connected to and furnish power for such industries as can absorb the energy for approximately 24 hours a day. We see in some localities water power developed solely for use in domestic service and small industries where the load exists perhaps less than eight hours a day. Frequently street railway systems are operated from hydro-electric power. That operating expenses are low in a hydro-electric development because no fuel is consumed is the conclusion drawn through the lack of information regarding the subject. Interest charges on

the investment which, in normal times, average about three times the interest charges on steam power equipment, naturally form the largest part of the cost of a kilowatt hour generated by hydro-electric development.

"It will be necessary to assure capitalists a fair and certain return on investment before they will finance any new hydro-electric development. No one would be so foolish as to spend $2.00 to mine one ounce of silver for which he obtains a price, under present conditions, of $1.00; in other words, it is an economic waste of $1.00 to spend $2.00 to obtain $1.00. The same thing is true in the case of hydro-electric development; if you cannot get out of it more than the interest charges on your investment, no matter how good the site may be, no matter how great the demand may be, it is not economical to develop that power. We visited yesterday a hydro-electric plant which is a very good example of the thing I am trying to bring forth. Interest charges on the plant visited yesterday run anywhere from $18.00 to $20.00 a horsepower year; in other words, the interest charge on the plant at Hale's Bar is equal to the present power cost to the consumer at Niagara Falls.

"There are many places where water power can be developed, but at a cost which prohibits its use at the present time. On the other hand, there are many places where water power can be developed economically, and it remains for the engineers of today to study this question thoroughly, so that they may not go astray or let others go astray in the near future on this point. It is absolutely essential that hydro-electric development must be made a paying proposition; if not, financial interests will not go into it, and without the bankers we are unable to develop any hydro-electric power. We have been shown that it costs no more to operate a hydro-electric plant at full capacity 24 hours a day than it costs to operate it for about one hour a day, whereas the returns from utilization 24 hours a day is necessarily 24 times the return for one hour. As a general proposition, if the connected load to a hydro-electric plant does not consume that power every hour of the day, there is an economic loss involved. There are, of course, a few special cases where this is not absolutely correct, but they are few indeed. Competent engineers have stated that there is no hydro-electric development in the United States



Dam and Power House, Hales Bar.

Site of Proposed No. 2 Dam at Muscle Shoals, Tennessee River.

School Children Greeting Party at Sheffield, Ala.

Under the Trees at Muscle Shoals, Ala.

Lock No. 9 at Muscle Shoals, Tennessee River, Ala.

that it will pay to develop, if the full load is not absorbed by consumers for at least 40 percent of the time. What I am trying to show is this, that such load as domestic house lighting and heating, street railway operation, and ordinary equipment, where these are the sole sources of income, should not be connected to a hydro-electric plant. On the other hand, an electrochemical load which is usually of 24-hour duration, as well as certain metallurgical processes which have been developed recently, will be looked to as the main sources of income for hydro-electric development. On the other hand, steam power, being relatively cheaper in installation cost, is not handicapped with a large interest charge and its major cost per kilowatt hour, of course, is coal. Or in other words, steam power is very aptly fitted to loads of the character of street railways, which have two large peaks a day and one small one, and to loads such as domestic or house lighting and heating, or small industrial plants.

"The ideal situation, of course, would be to have a hydro-electric development large enough to supply the continuous demands in any locality, with a steam plant floating upon the line which would absorb these peaks. It is absolutely certain that the public in general is not thoroughly conversant with the fact that hydro-electric power is not cheap for fluctuating loads. This is evident because we see in our neighboring country, Canada, a large political machine organized for the purpose of developing hydro-electric power to serve the householder. The people in some parts of Canada, today, are receiving power at a price much less than it costs to develop it, and not alone that, but as long as it is a political machine or Government institution, the people necessarily will not worry, as the deficit will be made up in taxes and the large corporations will in turn pay the major portion of these taxes. It is indeed a very fine institution for political purposes, and the day will be a serious one for this country when such a practice is added to our political condition. It remains, therefore, for you engineers to make yourselves thoroughly acquainted with the theory of this subject; make yourselves acquainted with all the facts and figures concerning it, and then do not stop there, but go forth throughout the entire country into all the localities you represent and present this same subject in its proper light to your people at home, in order that

we may preclude any possibility of such a situation arising in this country. Remember also that the economic value of the industries connected to hydro-electric power are a hundred times greater than the power development itself, and through the lack of foresight in this regard our political institutions at Washington, placing too much importance upon one feature, have held in check the development of the electrochemical industry of this country which would have added enormously to our economic wealth."*

Mr. N. T. Wilcox, of the Mississippi Power Company, Keokuk, Iowa, addressed the company as follows:

MR. WILCOX: "I did not expect to be called upon to say anything here today, but this meeting is an inspiration and I wish to bring to you and to express the great interest of those who have had to do with the development of the great power on the Mississippi at Keokuk. We have been through the same trouble in the way of development and getting support that you have.

* Mr. C. M. Jesperson, who was present, has communicated the following comments upon Mr. Winder's address:

"From the standpoint of all concerned, the operation of any plant at one hundred percent load factor is the acme of perfection, for the reason that it enables the power producer to operate with the lowest overhead costs, and thereby sell power to the consumer at a low rate. This condition is never reached, for commercial reasons with which every one is conversant.

"The idea of every power plant engineer is therefore to approach this point as nearly as possible, and to that end before the installation of a power plant the district is thoroughly canvassed and the load estimated both as to kilowatts and kilowatt hours, and, if possible, new industries are fostered to take as large an output as possible, and the plant designed on this basis along with the local conditions of available hydro-electric power and fuel supply, with an allowance for future increase. Then the rates are fixed, based on consumption and load factor the larger consumers obtaining the lower rates and the higher load factors likewise lower rates. If the rates can be set low enough to obtain the load, 'All's Well.' If not, the project is not feasible. No golden rule can be adopted as to what projects can be developed, but each case brings up new conditions to affect the judgment as to the possibilities of development. Some points have plenty of cheap fuel and no water supply within economic transmission distances, whereas other localities have easily developed water powers with high-priced fuel.

"Engineering studies of these situations would probably show one required a steam plant, and the other a hydro-electric plant, regardless of the load. They would also show the operating conditions under which the stand-by station should be operated. There are conditions which would call for exactly the opposite operation from that suggested by Mr. Winder. For instance, one installation in this country has hydro-electric power developed sufficient to handle its maximum load. In times of dry weather it is necessary for the stand-by steam plants to supply the kilowatt hours which can not be developed in the river. These steam plants are therefore operated at maximum economy, *i. e.*, as nearly 100 percent load factor as possible, and the hydro-electric units take the peaks. The stand-by plants have furnished at times power for electro-metallurgical purposes on this basis. The decreasing kilowatt-hour cost on a steam plant with increasing load factor must be kept in consideration at all times, although this is not as great a factor in steam production as in hydro-electric.

"The development of hydro-electric power in the United States is one requiring the most profound consideration by the engineers of the country, as well as by the bankers and politicians, and it is only by co-operation that this can be solved to the good of all concerned. Each project requires separate study before its feasibility is determined, and it must be realized by the financial backers that it is not a gold-mining proposition, but one requiring sound judgment to secure commensurate returns on the investment."

Long prior to the Civil War, Robert E. Lee, then a lieutenant in the U. S. Army, first pointed out the possibilities of development of the hydraulic power at Keokuk. For forty years or more local people dreamed of it, worked on it as you are working on this, and finally were able, after the development of engineering and electrical installation in the way of the transmission and the development of cheap Portland cement, to obtain the development which they had so long dreamed of.

"The Keokuk plant is now getting well loaded and is doing its part; possibly in a rather different way than will be done here, in that we will have more of the short-hour load resulting from the different local market conditions existing at Keokuk. We do not possess the same wonderful natural mineral resources over and above the water power development possibilities which you have here; but, notwithstanding that, we have our peculiar fields of opportunity. We find that there are many things in the way of recent development in electrochemical and metallurgical work which have enabled us to make our plant a success. You will have a larger amount of power ultimately than we have and in addition you have all these wonderful resources, and I know you will obtain a development which will meet the expectations of your ardent people who have been earnestly planning for so many years. I refer to Col. Worthington and others.

"I wish to extend to you our greetings and wish you Godspeed and to congratulate you on the fact that you are able, at this critical time, to do so much for the country that we all love so dearly." (Applause.)

The Secretary of the Society was then called upon, and made the following remarks:

Dr. J. W. Richards: "My friends, this scene is an inspiration, and I think I have the easiest task of anyone on the platform, to speak about the American Electrochemical Society. Founded in Philadelphia, in 1902, with an initial membership of 350 members, it now has a membership of very nearly 1,700. It has published 32 volumes of Transactions, averaging about 500 pages each, which constitutes the largest reservoir of electrochemical information there is in print. Our meetings, twice a year, have been intensely stimulating to all those who come to them, and that has

been one of the chief functions of the Society. The bringing together of the professors from the universities, and the toilers in the works, the dreamers and the inventors, the patent lawyers and the business men, all who are interested in any way in electrochemistry (and all such are eligible to become members of our Society) has resulted in a stimulus which cannot be measured in dollars, and in friendships which cannot be measured in words. This meeting is an innovation. It is the first time that we have taken an electrochemical tour, and I am sure that it will not be the last. I wish to speak of the relation of the Society to the industries, because the stimulus which the Society gives to the scientist in the laboratory finds its fruition in the stimulus which it gives to the technical man in the works. If it was only to stimulate the laboratory study of electrochemistry, the Society would lose at least half, I think more than half, of its right to exist. The aim and object of the Society is to make scientific research and scientific facts and scientists useful to the development of the industries, and if it does not do that it fails in its chief purpose. The industries are fundamentally based upon imagination, a vision of someone who knows some facts and can bring them together for useful purpose. Now those facts are gathered in the laboratories; you cannot evolve them from your inner consciousness, and therefore the man who works in the laboratory discovering the facts is fundamentally the one who supplies the seed from which grow the electrochemical industries. The inventor, the man of imagination, is often not the worker in the laboratory, but the man who uses the information obtained by him and puts it into useful effect. And then we have the vast number of toilers in the works, practical men, men who are able to use the information which is given to them, and they constitute the remaining and the most effective part of the whole institution.

There was an electrochemical society existing before ours, not in America, but in Germany, and the work of the Bunsen Gesellschaft in Germany has had a very large share in the preparedness of Germany for war and in the strength of her industries. It is a fact, gentlemen, that but for the electrochemical methods of fixing the nitrogen of the air, Germany would have had to throw up her hands and quit the war in six months. It was that fact which so impressed the members of the Naval Consulting Board

that Dr. Baekeland, a past president of this Society, whose name has already been mentioned here today, brought in a resolution that this Government was not fulfilling its duty, it was overlooking a very obvious duty, in not creating a large nitrate industry in our own country. After discussion of this matter the Naval Consulting Board advised the Secretary of the Navy to apply to Congress for funds for putting up the nitrate plants.

"The ideas which have come forth in meetings of this Society from members of this Society have often stimulated others. I want to give one instance only. We have on our program a paper to be read at Birmingham by Mr. Flinterman on the electric steel casting industry. He was at our meeting in Detroit last year, and, hearing an abstruse paper on the study of electric furnace currents by means of the oscillograph (the apparatus which gives the shape of the electric wave which passes through the furnace) the conclusions of the paper caught Mr. Flinterman's attention. He said 'There is probably a way of improving our practice,' and he set to work with that idea. Now he comes to this meeting of the Society with a paper telling how he has applied the information in that scientific paper, and he has so improved the running of his furnace thereby that while last year he was on the point of adding a third furnace to his two, in order to increase their works capacity, he now says he is not building the third furnace, because he is getting as much out of two furnaces by the application of this improvement as he expected to get out of the three. (Applause.) That is one small illustration of the great fertility of ideas which are dropped at our meetings and which spread, not only throughout those present at the meetings, but, by means of our Transactions, throughout the whole country, throughout our whole membership. We are planting seed every time we have a paper with ideas in it read before our Society, and especially when we discuss it and help to point out the weak points and congratulate the author on the strong points.

"It is this fertilizing of the whole field of the science of electrochemistry and its practical applications, which is the function of this Society. No man concerned with electrochemistry, scientifically or practically, can afford to stay outside it." (Applause.)

Mr. Waldo, of Muscle Shoals, next spoke, as follows:

Mr. W. G. Waldo: "For the last ten years we have followed the progress of electrochemistry in this country with intense interest. We have seen industry after industry conceived by Americans, operated and owned by Americans, driven to foreign countries that were as uninviting as the bleak coast of Norway. We have seen them go as far in Canada as the Shawinigan Falls in the Province of Quebec, and we have been very impatient with our own nation. We have felt that here at Muscle Shoals we have all there was to offer at Quebec and in Norway, and then some, and the chief value of it lay in the fact that it was in the United States of America. (Applause.)

"We have felt proud of being able to throw some of these industries into the scales in behalf of our Government in this great crisis; we have felt that here we had the chance to show the Government, to show the nation as a whole, that there were at Muscle Shoals and in this vicinity, resources and opportunities for development which were unknown to even the best informed among those who are supposed to know these things.

"Now, if we can get careful scientific investigation of their nature, based upon knowledge and not upon guesswork, in the development of these materials, we will have accomplished something—something which will bring the South to its own.

"I should like to say one word about what we really have here. We have on display some maps and graphics which tend to show that there are 660,000 H.P. in this stream. So there are, but there is a string tied to it; the dam which is to be built at the site that we will inspect a little later in the afternoon will, under the present conditions, warrant the installation of only 165,000 H.P. Ultimately it is hoped that there will be established at this point 480,000 H.P. This amount of power cannot be had from the run of the river at Muscle Shoals; it must be had from a combination of the run of the river power which we have here combined with two great storage reservoirs over in the hills not far distant. Those storage reservoirs have not yet been authorized; that is, the complete improvement has not been authorized by the Government, for it will require a third dam above here, six or eight miles from where we are sitting, and two reservoir dams, one at Cherokee Bluffs on the Tallapoosa River, the other one on Little River.

"When we speak of developing 660,000 H.P., gentlemen, we are speaking about what can be done and what we are bound to do when this great development is completed; but we need assistance in this matter, we need the advice and moral support of such organizations as this. We want to develop here a center of power which shall rival Niagara Falls in its magnitude and usefulness, but we cannot do that with the present authorized dam number two alone. While this dam is being completed—at the same time, if possible—we must have these other reservoir powers developed, so that the whole project may be tied together in one magnificent development, and let me ask that this Society shall, if it sees fit, pass suitable resolutions endorsing the Muscle Shoals proposition, not simply as a development of 165,000 H.P. but as a great prospective development of 660,000 H.P.

"We speak sometimes in superlatives when we talk about Muscle Shoals, but that is justifiable, for Dam No. 2 will be the greatest dam in the world: its 1,200,000 cubic feet of concrete will put it ahead of the Kensico Dam, and Dam No. 3, with its 6,725 feet of length will be the longest dam in the world, longer than the Assuan Dam of the Nile, which has 6,700 feet to its credit. The Government has already provided and is providing industries here in the shape of these nitrate plants, which we estimate will utilize ultimately some 260,000 H.P. That will leave us 400,000 H.P. for other industries.

"We hope, and it is our fervent desire, that out of that 400,000 H.P. there shall be set aside a certain amount which shall be available for electrochemical purposes in a way which hitherto has not existed. By that we mean just this: The electrochemist is not in general a man of great wealth; he is one of our professional men of the country who has, we will say, more in his head than in his pocketbook; (laughter) so that he is not able himself to finance any great development for the purpose of experimentation. But if the Government will come here and set aside a certain amount of this power and a certain space within these great buildings or other ones, and say to the electrochemists: "Come here, Mr. Electrochemist, and hitch on; here is the power, you shall have it; here is the space, it is all yours and no charge; all we ask is that you shall keep this country in its proud position of foremost in the electrochemical industry," (applause) "then the

American electrochemist will find at Muscle Shoals the great laboratory which he seeks, and then will come to this great power site the industries which our country needs. Then, and not until then, will we realize something of what the future has in store for Muscle Shoals." (Applause.)

PRESIDENT FINK: We have been presented here with a magnificent souvenir book of Muscle Shoals, and in behalf of the Society I want to extend our sincere thanks and gratitude to Colonel Worthington and the Tennessee Power Company for the handsome gift.

Mr. Isobe, of the Suzuki Company, one of Japan's great commercial companies, greeted the audience as follows:

MR. FUSANOBU ISOBE: "I have the honor and I take the pleasure to speak to you just one minute and tell you how much we Japanese people particularly have enjoyed your hospitality and the kindness you have shown us in the last few days. My friends, we think that you Americans, like our Japanese people, have somewhat overestimated German science and German civilization. We ought to have more confidence, we ought to have more courage to do more research work, of which we have not done very much in the last few years. If I go home in a few weeks, I promise to you that we Japanese are going to publish all our electrochemical research work through the American Electrochemical Society's Transactions. Next thing, when will you come to Japan to have a meeting of this American Electrochemical Society? I would like all of you to come to Japan just after the war. I think all of you are too busy now to go over there, but after the war I want you to come. I want you to see what we have done in Japan in the last few years, what we have done for the uplifting of our nation through electric and chemical industries. I want you to see that, and we will open all our factories, if possible, to you and let you see what we are doing. (Applause.) And we are going to show you the same hospitality and kindness which you all, my dear friends, have shown to us. I thank you." (Applause.)

At 4.30 P. M. the return trip to Florence was begun, first several miles by motor railway car on the bank of the canal, and the rest of the way down to Florence from lock number five on a

GROUP AT HOTEL TUTWILER, BIRMINGHAM, ALABAMA, MAY 3, 1918.

TWILER, BIRMINGHAM, ALABAMA, MAY 3, 1918.

gayly-decorated barge towed by a stern-wheel river steamer. Passing the proposed site of dam number one, and a blast-furnace plant on the bank, the vessel tied up at the dock in Florence, whence automobiles were taken to the Jefferson Hotel. Col. C. W. Ashcroft, W. H. Mitchell and Frank Nolan constituted the capable entertainment committee at Florence, which provided a complimentary dinner, and subsequently, at 7 P. M., invited the visitors to an informal reception at the Elks' Home, to meet the prominent citizens of Florence. The reception was the occasion of some more speeches, after which, at 8.30 P. M., electric cars were taken back to Sheffield, whence the special train left at 9 P. M. for Birmingham.

PROCEEDINGS OF FRIDAY, MAY 3

Birmingham, Ensley and Bessemer

Arriving at 6 A. M., breakfast was taken at the Hotel Tutwiler, where the party was greeted at 8.45 by the Local Committee and their friends. The committee was as follows: Wallace L. Caldwell, Chairman; John L. Kaul, O. G. Thurlow, Culpepper Exum, Emmet O'Neal, Karl Landgrebe, Martin J. Lide, Frank P. Glass. Mrs. W. D. Nesbitt, Chairman of the Ladies' Committee.

Before starting, group photographs of the party were taken outside the Hotel Tutwiler. The procession of some fifty automobiles, each bearing a banner inscribed with the name of the Society, then passed through the principal streets of Birmingham, and arrived at 9.30 A. M. at the Ensley Blast Furnace Plant of the Tennessee Coal, Iron and Railroad Company. Here a white lime trail guided the party through the plant and around the blast furnaces, giving them a quick but satisfactory view of the immense works.

At 10 A. M. the party arrived at the Ensley Steel Plant of the same company, where an hour and a half was spent. The party was divided into two small companies, each under an official of the plant, and a most satisfactory inspection was made of the Bessemer plant, open-hearth furnaces, slag-grinding plant, coal mine head, power plant and rolling mills. The whitewash trail through all the buildings from start to finish was voted a brilliant idea, simple and highly practical.

The complimentary luncheon at noon took the form of a barbecue in the woods at Bayview, on the banks of the water power reservoir, a few miles from Ensley. A negro orchestra sang and played Southern melodies, which were greatly enjoyed by the Northern visitors. The ladies were taken motor-boat trips on the lake. After luncheon, the party was assembled on the sloping bank, and addressed by the Hon. Emmet O'Neal, ex-Governor of Alabama.

Leaving Bayview at 1.30 P. M., the party passed through several coal-mining centers, stopping a few minutes at the Edgewater Coal Mine of the Tennessee Coal, Iron and Railroad Company, to see its community store, and arrived at 2 P. M. at the Fairfield By-Product Coke Plant of the same company. Here was seen the loading and emptying of several coke ovens, and the by-product plant.

"Southern Comfort," Edgewater Coal Mines Store, Birmingham, Ala.

Passing the site of the new Fairfield steel works, which plant is just commencing construction, the party arrived at 3 P. M. at the Fairfield plant of the American Steel and Wire Company. Here were seen the rolling of ingots to rod, the drawing of rod to wire, and the manufacture therefrom of spikes and nails. The electric welding machine for making wire fencing claimed special attention, also the continuous wire galvanizing machine.

After a trip through the South Highlands residential district, the Birmingham Country Club was reached at 5 P. M., where in addition to light refreshments and tea provided by the ladies, many of the party enjoyed greatly the club's shower bath facilities.

After enjoying the rest and refreshment of the beautiful club

Sloss-Sheffield Furnace, Florence, Ala.

Home of Helen Keller, Tuscumbia, Ala.

Birmingham Country Club.

Dipping Out "Brunswick Stew" at Barbecue Luncheon, Bay View Reservoir, Birmingham, Ala.

Governor E. O'Neil Addressing Party at Bay View Reservoir.

Preparations for the Barbecue at Bay View Reservoir.

house, whose balconies overlook Birmingham and vicinity, the visitors returned to the train, to gather later at the Hotel Tutwiler at 7 P. M., for the Complimentary Banquet, where the visitors were guests of the Birmingham Chamber of Commerce. Arthur C. Crowder, president of the Chamber of Commerce, presided, and the Rev. Dr. Frank Willis Barnett invoked the divine blessing. After a highly enjoyable meal, Mr. Crowder called upon the Hon. Emmet O'Neal to greet the visitors and tell them of the resources of the Birmingham district.

At the close of the banquet, at 9 P. M., a Technical Session for reading and discussion of papers was held in the ballroom of the Hotel Tutwiler. The Technical Society of Alabama had held a meeting in Birmingham the day before, and many of its members stayed over to greet the visitors and attend this evening's technical session. Dr. Eugene A. Smith, State Geologist of Alabama, delivered an address on the Mineral Resources of Alabama, which is printed in these Transactions.

Papers were then read in abstract and discussed as follows: G. D. Van Arsdale and C. G. Maier (presented by Mr. Maier), E. F. Kern (abstracted by C. S. Witherell), F. C. Mathers (abstracted by G. B. Hogaboom), O. L. Kowalke and O. A. Hougen (abstracted by J. W. Richards), E. F. Kern (abstracted by C. S. Witherell), M. A. Hunter and J. W. Bacon (read by title), O. P. Watts (abstracted by M. deK. Thompson), C. H. vom Baur (abstracted by A. M. Hamann), W. K. Booth (abstracted by J. L. McK. Yardley), R. F. Flinterman (abstracted by F. J. Tone), O. P. Watts and C. T. Fleckenstein (read by title), S. A. Reed (read by title), Earl M. Anger (read by title)—which are printed in full, with discussions, in these Transactions.

President Fink then called President-elect Tone to take the chair. After some brief remarks on the lessons of the trip and the work of the Society for the coming year, President Tone declared the meeting adjourned at 11.45 P. M., and the special train left Birmingham at 12 P. M. for Anniston.

PROCEEDINGS OF SATURDAY, MAY 4

Anniston, Alabama

Arriving at 7 A. M., the party assembled for breakfast at the Anniston Inn, as guests of the following members of the Local Committee:

W. E. Lloyd	Scott Roberts	B. R. Sawyer
S. M. Caudle	H. R. Lee	Dr. A. N. Steele
Will Mallory	J. B. Carrington	N. E. Ory
W. A. White	L. L. Scarbrough	J. C. Sproull
L. W. Jackson	W. G. Crutchfield	Homer Lanford
Dr. R. L. Hughes	C. R. Bell	J. M. Stillwell
E. G. Bosworth	C. M. Woodruff	C. E. Ard, Jr.
Hillyer Robinson	W. H. McKleroy	Gordon Jones

After breakfast, the gentlemen named took their guests in automobiles for visits to the local industries.

The first works visited was the new plant of the Southern Manganese Corporation, where three electric furnaces were running on ferro-silicon, being leased to the Electro-metallurgical Company of America, and three on ferro-manganese. The latter were opened to inspection, and under the direction of Mr. Theodore Swann and his assistants every item connected with the source of supply of manganese ore, the running of the furnaces and the nature of the product and slag was freely communicated. Great admiration was expressed by the visitors for the business-like lay-out and the efficient operation of the plant.

The visitors were then taken to the old plant of the Southern Manganese Corporation, where similar but smaller ferro-manganese furnaces were seen in operation, and also electric furnaces for converting steel scrap into low-phosphorus pig iron.

The party then visited the plant of the Anniston Steel Company, where a Heroult electric furnace was seen in operation making steel castings.

Returning to the station, good-bye was regretfully said, and the special train started at 12 M. on its return to Washington *via* Atlanta, Ga., which was passed about four o'clock in the afternoon.

SUNDAY, MAY 5

Washington, D. C.

The special train arrived at the Union Station at 2.45 P. M., enabling many to catch the afternoon trains to Philadelphia and New York, and the night trains for more distant points.

The general consensus of opinion among those participating in the trip was that it had been highly profitable to every one of the travelers, as well as of benefit to the communities visited. The North had certainly been brought nearer to the South, industrially, commercially and socially.

It was a source of satisfaction also that the traveling arrangements worked out smoothly, the trip was made within the very moderate estimated expenses, and the emergency guarantee fund was returned intact to the participants.

(The photographs used in illustrating the story of the Southern Trip were kindly supplied by Messrs. C. F. Roth, W. M. Saunders, Jr., Y. Takikawa, R. P. Calvert and J. Kurahashi.)

MEMBERS AND GUESTS ON THE TRAIN

Members.

J. T. Baker
Wm. H. Beck
Geo. M. Berry
Dr. R. P. Calvert
S. C. Carrier
W. H. Carrier
Ralph T. Chace
E. H. Clapp
F. G. Cottrell
Alfred H. Cowles
H. T. Darlington
R. W. Davis, Jr.
J. V. N. Dorr
F. P. Dunnington
Howard Ecker, Jr.
Harrington Emerson
C. G. Fink
J. A. Fogarty
H. W. Fox
Richard H. Gaines
H. Gesell
A. E. Gibbs
Chas. B. Gibson
G. C. Given
M. L. Griffin
A. M. Hamann
Carl Hering
A. T. Hinckley
B. H. Hite
Geo. B. Hogaboom
L. S. Holstein
R. P. Hommel
A. H. Hooker
K. Inui
Fusanohu Isobe
Wm. F. James
D. W. Jayne
C. M. Jesperson
Lyman C. Judson
H. W. Kellogg
Samuel L. Kent
Casimiro Lana
F. G. Liljenroth
Eric A. Lof
Chas. P. Madsen
Chas. G. Maier
Charles A. Mann
C. W. Marsh
R. M. Martin
D. L. Mathias
W. Wallace McKaig
Millard W. Merrill
Dwight D. Miller
H. A. Morin
Emil Mueser
J. Malcolm Muir
E. F. Northrup
H. C. Parmelee
R. H. Pickens
O. C. Ralston
Henry E. Randall, Jr.
Jos. W. Richards
E. G. Rippel
Chas. F. Roth
G. A. Roush
Pedro G. Salom
Walter M. Saunders
Carl G. Schluederberg
Acheson Smith
F. T. Snyder
C. C. Speiden
H. N. Spicer
E. K. Strachan
E. C. Sullivan
E. M. Symmes,
Kozo Tabata
Yasuo Takikawa
M. deKay Thompson
L. S. Thurston
F. J. Tone
T. M. Uptegraff

L. D. Vorce
G. D. Van Arsdale
H. Lee Ward
Joel H. Watkins
G. E. Weissenburger
R. H. White
L. W. Williams
C. A. Winder
Chas. Wirt
C. S. Witherell
J. L. McK. Yardley

Guests.

Y. Amenomiya, Osaka, Japan.
G. K. Anderson, Philadelphia, Pa.
E. R. Bartlett, Niagara Falls, N. Y.
Mrs. F. G. Cottrell, Washington, D. C.
Mrs. A. H. Cowles, Sewaren, N. J.
A. C. Cummins, Duquesne, Pa.
H. Dedichen, Cambridge, Mass.
J. B. Douthit, Clemmons, N. C.
Mrs. H. Emerson, New York City
H. B. Faber, New York City
Mrs. C. G. Fink, New York City
R. U. Fitting, New York City
K. Hirono, Osaka, Japan
W. S. Hooey, Palmerton, Pa.
W. H. Irwin, Chicago, Ill.
Y. Kato, Tokio, Japan
Mrs. H. W. Kellogg, Niagara Falls, N. Y.
R. Knudsen, Boston, Mass.
J. Kurahashi, Tokio, Japan.
A. B. Larchar, Great Works, Me.
R. W. E. Moore, East Pittsburgh, Pa.
S. Nakahara, Osaka, Japan
H. C. Neeld, Niagara Falls, N. Y.
C. R. Parkinson, Rittman, Ohio
Mrs. H. C. Parmelee, New York City
Mrs. E. G. Rippel, Buffalo, N. Y.
Mrs. G. A. Roush, Bethlehem, Pa.
Mrs. P. G. Salom, Philadelphia, Pa.
Miss Salom, Philadelphia, Pa.
W. M. Saunders, Jr., Providence, R. I.
E. K. Scott, New York City.
W. H. Shearman, New York City
W. H. Stone, Baltimore, Md.
J. A. Switzer, Knoxville, Tenn.
T. Tanabe, Kyushi, Japan
J. M. Weiss, New York City
A. H. White, Washington, D. C.
R. H. Whitney, New York City
N. T. Wilcox, Keokuk, Iowa
Mrs. C. Wirt, Philadelphia, Pa.

ANNUAL REPORT OF THE BOARD OF DIRECTORS

To the Members of the American Electrochemical Society:

The following are some of the important items of business transacted by your Board of Directors during the past year:

A joint Committee of the Society consisting of Messrs. Fitz-Gerald, Addicks and Lidbury, was appointed to co-operate with the electrochemical division of the National Electric Light Association.

Prof. W. D. Bancroft was approved as representative of this Committee upon the Electrochemical Committee of the National Research Council.

The Board authorized the investment by the Society of $2,000 from cash on hand in each of the first, second and third Liberty Loans.

A committee of three, consisting of W. S. Landis, chairman, C. G. Atwater and F. K. Cameron, was appointed as a Committee on Artificial Fertilizers to co-operate with the Department of Commerce in the matter of stimulating the food supply of the country.

The Board appointed C. A. Doremus and Joseph Bijur as representatives of the Society on the joint "War Committee of Technical Societies," to co-operate with the Naval Consulting Board in handling war problems in which engineers can assist.

The Board contributed for the present calendar year the dues requested for the War Committee of Technical Societies, upon which this Society is represented by two members. The contribution requested is fifteen cents per member for each year.

Mr. J. Malcolm Muir was appointed to represent the Society upon the Census Committee of the Engineering Council of the Engineering Society of New York City.

The Board authorized $50 contribution to the International Commission issuing the "Annual Tables of Physical and Chemical Constants."

A proposition from the Faraday Society was discussed and accepted, by which the Faraday Society furnishes its Transactions to any of our members desiring them for $2.25 per annum, in consideration of reciprocal terms to the members of the Faraday Society.

SECRETARY'S ANNUAL REPORT

To the Board of Directors of the American Electrochemical Society:

GENTLEMEN: In 1917 the Society held two general meetings, one at Detroit, Michigan, May 2, 3, 4 and 5, 1917, at which the attendance was 80 members and 115 guests, total 195; the second at Pittsburgh, Pa., October 3, 4, 5 and 6, 1917, at which the attendance was 164 members and 189 guests; total 353. The Transactions of the spring meeting include 28 papers, and those of the fall meeting 30 papers.

In 1917 there were issued and distributed to our members two volumes of the Transactions: Volume XXXI, the Transactions of the meeting in Detroit, Mich., May 2, 3, 4 and 5, 1917; Volume XXXII of the Pittsburgh meeting, October 3, 4, 5 and 6, 1917. These volumes contained 437 and 516 pages respectively.

The edition of Volume XXXI was 1300 copies, bound in cloth for distribution to our members; 50 extra copies for distribution in pamphlet form to authors of papers; 250 copies unbound to be kept in stock. The edition of Volume XXXII was 1300 copies

bound in cloth, for distribution to our members; 50 copies for distribution in pamphlet form to authors; 250 copies bound in paper for distribution to the Faraday Society; 200 copies sewed ready for binding, to be kept in stock.

The stock of Volumes on hand December 31, 1917, was as follows:

Volume	Bound in Cloth	Bound in Paper	Total
I	116	13	129
II	149	0	149
III	56	0	56
IV	82	233	315
V	35	234	269
VI	139	10	149
VII	49	195	244
VIII	70	321	391
IX	68	315	333
X	65	244	309
XI	67	266	333
XII	57	254	311
XIII	166	0	166
XIV	192	15	207
XV	182	223	405
XVI	182	289	471
XVII	104	19	623
XVIII	132	515	647
XIX	0	531	531
XX	1	535	536
Index of Vols. I—XX	369	68	437
XXI	0	554	554
XXII	0	546	546
XXIII	243	293	536
XXIV	351	0	351
XXV	5	537	542
XXVI	23	519	542
XXVII	50	538	588
XXVIII	24	551	575
XXIX	206	572	778
XXX	245	40	285
XXXI	126	250	376

Condition of the Society in regard to membership in 1917:

Members January 1, 1917		1,541
Elected and qualified as members in 1917		235
		1,776
Resignations in 1917	32	
Deaths in 1917	7	
Dropped for non-payment of dues	57	
		96
Members December 31, 1917		1,680

Condition, April 28, 1918.

Members January 1, 1918	1,680	
Qualified as members to April 25th	48	
		1,728
Deaths	2	
Dropped for non-payment of dues	76	
		78
Members April 25, 1918		1,650

Financial Statement.

Receipts in 1917.

Cash assets beginning January, 1917, account		$4,146 01
Entrance fees	$1,100 00	
Current dues	5,865 22	
Back dues	584 89	
Advance dues, 1918	770 00	
Advance dues, 1919-22	20 00	
Subscriptions to 1917 bound Transactions	3,540 00	
Subscriptions to 1918 bound Transactions (paid in adv.)	505 00	
Sale of publications	1,814 84	
Interest on bonds and bank accounts	288 09	
Sale of extra reprints	139 53	
Sale of Society pins	30 00	
Sale of silver used for research purposes	214 44	
Differential on investment	78 28	
Subscription for Faraday Society Transactions	94 50	
		$15,044 79
		$19,190 80

EXPENDITURES IN 1917.

Secretarial appropriation	$1,700 00	
Office printing	616 83	
Printing of Volume XXX	1,007 55	
Printing of Volume XXXI	1,870 45	
Printing of advance copies and discussions	2,323 86	
Engraving	393 25	
Extra reprints	137 13	
Binding of volumes	438 67	
Office postage	351 65	
Express and postage for volumes	233 78	
Advance copies postage	500 00	
Office expenses	421 93	
Expenses of meetings	655 15	
Office equipment	296 16	
Storage and insurance	206 43	
Membership Committee	19 66	
Publication Committee	138 29	
Local sections	125 00	
Duty on Faraday Society Transactions	41 15	
Annual Tables of Physical and Chemical Constants	50 00	
Miscellaneous	30 00	
Investment in Liberty Bonds	4,000 00	
		$16,556 94
Cash assets beginning January, 1918, account		2,633 86
		$19,190 80

TREASURER'S ANNUAL REPORT, 1917

January 1, 1917, cash balance	$4,146 01	
January 1, to December 31, 1917: Receipts	15,044 79	
		$19,190 80
Expenditures, 1917		16,556 94
December 31, 1917: cash balance		$2,633 86
Commonwealth T. I. & Trust Co.	$1,373 83	
Wilbur Trust Co.	1,210 03	
Cash box	50 00	
		$2,633 86

We have examined the above statement of account of receipts and expenditures for the year 1917, and find the same to be correct.

We also report $3,100 Philadelphia Electric Co. Bonds and $4,000 U. S. Liberty Loan Bonds in the box of the Society in the Safe Deposit Vaults of the Commonwealth Title Insurance and Trust Co., Philadelphia, Pa.

CARL HERING,
S. S. SADTLER,
Auditors.

REPORT OF TELLERS OF ELECTION

Following is a list of votes cast in the election of officers for the year 1918-1919.

For President: F. J. Tone, 193; C. G. Schluederberg, 28.

For Vice-Presidents: Acheson Smith, 200; H. W. Gillett, 156; R. Turnbull, 129; W. R. Whitney, 59; L. Addicks, 37; L. D. Vorce, 37; J. Takamine, 21; C. G. Schluederberg, 1.

For Managers: C. F. Burgess, 164; E. L. Crosby, 147; C. G. Schluederberg, 137; W. R. Whitney, 65; F. A. Lidbury, 52; L. Addicks, 34; G. B. Hogaboom, 33; O. P. Watts, 26.

For Treasurer: P. G. Salom, 212.

For Secretary: J. W. Richards, 214; A. T. Hinckley, 1; G. A. Roush, 1.

Signed,

BARRY MACNUTT,
S. S. SEYFERT,
G. A. ROUSH.

The President announced the following elections to office as the result of the report of the Tellers:

President: F. J. Tone.

Vice-Presidents: Acheson Smith, H. W. Gillet, R. Turnbull.

Managers: C. F. Burgess, E. L. Crosby, C. G. Schluederberg.

Treasurer: P. G. Salom.

Secretary: J. W. Richards.

PROPOSED AMENDMENTS TO CONSTITUTION

The following amendments to the Constitution were duly proposed and sent out to the members for their vote:

Article II, Section now reading "1. There shall be only one class of members," substitute:

1. The Membership shall consist of Members and Honorary Members.

Add Section 3, as follows:

3. Honorary Members shall be those who by reason of valuable contributions to electrochemistry deserve special recognition by the Society.

Article III, add the following new Section 6:

6. Honorary Members shall be recommended over the Signatures of at least ten Members, and shall be elected only at the meeting of the Board of Directors in conjunction with a general meeting of the Society, and by the unanimous vote of the Directors present, a quorum being present.

Honorary Members shall pay no entrance fee or annual dues, and shall receive all the Publications of the Society.

The number of Honorary Members shall not at any time exceed ten, and not more than two shall be elected in any one calendar year.

The result of the letter ballot was 63 for and 6 against. The vote taken at the meeting was 25 for and 1 against the proposed changes, making a total of 88 for and 7 against. The chairman announced that the amendments were carried.

RESOLUTIONS PASSED BY THE BOARD OF DIRECTORS IN REFERENCE TO THE FEDERAL DYESTUFF AND CHEMICAL CORPORATION. (See page 7)

The following resolution was sent to the War Industries Board and to the Chief of Ordnance, War Department, Washington, D. C., on May 2, 1918:

"WHEREAS, Federal Dyestuff & Chemical Corporation has a plant at Kingsport, Tennessee, already constructed and in operation and equipped and ready to manufacture in large quantities explosives, intermediates and other products needed by our Government in the prosecution of the war, and

WHEREAS, The Board of Directors of the American Electrochemical Society during the 33d General Meeting held at Kingsport, Tenn., April 29, 1918, has found with surprise that the Federal Dyestuff & Chemical Company is not at present in the manufacture of such products for this Government and that a large portion of the plant is idle, now therefore be it

Resolved, By the Board of Directors of the American Electrochemical Society, that it is the judgment of this Board that the aforesaid plant should immediately be investigated by the Government as to its possibilities for the production of explosives and other war materials, and further

Resolved, That copies of these resolutions be respectfully submitted to the War Industries Board and to the Ordnance Department of the United States Army."

On May 14, 1918, the Secretary received advices from the office of the Chief of Ordnance "that on the 11th of May the Government completed all negotiations to take over the Federal Dyestuff and Chemical Company at Government terms."

REPORT OF THE PUBLICATION COMMITTEE

In preparing for the fall meeting of the Society held in Pittsburgh, October, 1917, thirty-four papers were submitted to the Publication Committee. Of these thirty-one were accepted, and three were rejected on the basis that they did not contain any information new to the Science.

In preparation for the spring meeting of the Society to be held in May, 1918, twenty-one papers were submitted, eighteen were accepted, one paper was held over for the fall meeting in order that the author might clarify some obscure passages, and two were

rejected, since they did not contain any information new to the Science.

A. T. HINCKLEY, *Chairman.*

MEMBERS ELECTED AND QUALIFIED

Since Last Membership List (January 31, 1918).

February 12, 1918:
A. R. Hitch
R. L. Frink
Wm. H. Beck
H. D. Lehr
Bertram Wood

February 14, 1918:
M. Fukuda
B. C. Condit
F. G. Breyer
P. J. Kruesi
J. B. Smith
C. Lana
G. C. Castle

March 12, 1918:
John Readette
J. F. Cullen
C. T. Eakin
S. Mine
G. C. Benson

March 21, 1918:
R. G. Brown
J. B. Black
T. M. Uptegraff
C. D. Wood
H. N. Spicer
F. E. Bash
B. Nilssen

April 25, 1918:
J. Pompeia
W. G. Waldo
G. C. Wilson
J. A. King
C. W. W. Crowther
J. H. Watkins
G. L. Casey
E. E. Thum
M. J. Kay
G. L. Davison

May 27, 1918:
Victor Yngve
S. C. Pitman
S. L. Kent

May 27, 1918—*Contin'd*
E. C. Sullivan
H. B. Faber
F. Isobe
J. A. Switzer
K. Tabata
S. Nakahara
T. Kurahashi
G. B. Heisig
Robert Cowan
J. W. Weitzenkorn
H. C. Brown
S. C. Hooker
H. L. Saums
J. N. Mahoney
P. G. Savage

June 13, 1918:
V. H. Gottschalk
M. Pasternak
C. J. Kryzanowsky
Gustav Egloff
A. L. Browne
Garret Schenk, Jr.
N. T. Wilcox
C. F. Landero
T. J. Keenan
C. L. Peirson
H. P. Bassett
J. C. App
James Brakes
J. H. Naiden
I. Kitawaki
C. K. Simon
Hans Gesell
H. F. Saunders
J. F. White
E. R. Cooney
F. McQuillen
C. C. Meigs
G. G. Marshall
A. C. Langmuir
F. C. Zeisberg
E. A. Rykenboer
J. R. Marble
E. K. Scott
A. H. Pugh, Jr.
R. P. Dinsmore

June 13, 1918—*Contin'd*
M. P. Cram
F. E. Brown, Jr.
J. C. Munch
G. Clinton
J. F. Adams
C. E. Sholes

June 20, 1918:
K. T. Wong
C. Kroll
F. W. Bunyan
W. J. Isbell
E. M. Wood
L. C. Judson
E. F. Cone
John Jicha
C. M. Carson
W. O. Quaile
H. H. Brunt
Rolf Knudsen
W. C. Dutton
Herman Dedichen
A. O. Kellogg
T. F. Golick
E. S. C. Smith
D. E. Allen
E. G. Sturdevant

June 28, 1918:
O. H. Klein
J. R. Lower
H. Hughes
H. V. Wright
Hyam Schwartz
F. T. Sisco
A. F. MacFarland
F. H. Peterson
R. H. Hummert
A. L. O'Brien
H. W. Matheson
P. B. Francis
L. M. Richard
F. H. Warner
R. P. Calvert
W. Harter
Dudley Willcox
H. F. Porter

July 25, 1918:
P. M. Nash
R. Gilchrist
L. K. Russell
H. P. Hood
St. B. Marshall
M. A. Knight
F. W. Oldach
W. M. Blanchard
A. M. Neff
C. N. Ferguson
L. J. Willien
E. M. Symmes
J. G. Dailey
Lyon Smith
E. H. Carus
W. R. Teeters
K. C. Nicholson
E. S. Taylerson
J. Takamine, Jr.
G. B. Frost
H. D. Braley
L. DuPont
A. P. Sachs
F. D. Haskins
W. J. Hund
H. B. Battle
J. N. Carothers
Geo. S. Smith
A. N. Anderson
H. D. Ruhm
M. A. Ceresole
J. M. Canfield, Jr.
Y. K. Chiang
T. W. Smith
C. F. Quaintance
J. S. Grasty
S. P. Kinney
G. Joselowitz
G. A. Lutz
J. T. Stoddard
C. E. Magnusson
W. H. Stone
C. P. Fox
A. E. Rhoads
A. R. MacPherson
H. L. Thompson
P. S. Brallier
W. D. Engle
H. E. Dunn
R. M. Martin
E. J. Berger
G. I. Sargent
E. B. Miller
A. C. Cummins
H. P. Corliss
G. N. Gardner
W. A. Wissler

July 25, 1918—*Contin'd*
H. B. Saeter
M. H. Morley
C. F. Coffin
F. W. Hogan
E. F. Seifert
J. W. Martin, Jr.
J. P. Marble
A. V. Graf
J. D. Stein
Chas. Pack
F. W. Kroemer
F. H. Schultz
H. E. Behnken
B. H. Handy
T. P. Maynard
L. G. Patterson
H. S. Sands

August 22, 1918:
F. B. Holmes
H. Clements
W. H. Fulweiler
A. A. Wagner
W. H. Bell
A. C. Reed
E. D. Koepping
J. H. Herron
J. C. Platts
H. L. Doyle
S. W. Haas
A. B. Cummins
F. D. Abbott
E. J. Pranke
J. E. Schott
C. Zischkau
Robt. Nivison
P. J. O'Reilley
N. B. Brown
W. J. O'Neill
H. McMillen
Manuel Zamora
Gonzalo Y. Font
F. J. Ryan
G. W. Pickard
A. M. Plumb
C. T. Evans
Geo. Walters
C. J. Rottmann
A. N. Barron
F. F. Jackson
N. N. Dalton
W. A. Frederick
M. B. Gottlieb
Y. Tada
W. R. Gailey
J. E. C. Valentin

Aug. 22, 1918—*Contin'd*
W. H. French
Wm. Grelck
D. A. Russell
H. W. Walter
F. V. Andreae

September 13, 1918:
H. M. Burlage
John Hedalen
C. H. M. Roberts
G. M. Berry
W. A. Gruse
E. M. Barr
P. A. West
W. E. Mitchell
T. B. Walker
D. F. Higgins
G. Fuseya
D. P. Smith
W. R. Loveman
O. Sowers
L. Sturbelle
F. A. Fahrenwald
H. F. Klemm
J. D. Hoff
J. St. Grumbling
T. E. Dunlop
J. A. Prochazka
R. W. E. Moore
C. S. Hollander
N. L. Towle
J. E. Haig
E. C. Higgins
I. Itoh
G. Tysland
Y. Kato
Henry Arnstein
P. B. Watson
W. E. Spandow

October 23, 1918:
M. L. Hartman
W. H. Cohen
E. F. Bainbridge
P. F. Berk
Max Knobel
F. E. Stockelbach
W. B. Woodbridge
Burr Humiston
L. B. Moorhouse
W. B. Featherstone
J. T. Naylon
C. E. Cummings
J. O. Small
K. Ikeda
F. W. Zons

Presidential Address delivered at the Thirty-third General Meeting of the American Electrochemical Society at Knoxville, Tenn., April 30, 1918.

ELECTROCHEMISTRY AND NATIONAL ECONOMY

By Colin G. Fink.

The American Electrochemical Society considers itself very fortunate indeed to have the opportunity of undertaking this most interesting and highly instructive trip through the Appalachian South. What we have already seen more than convinces us that the Appalachian South is rapidly developing into one of the leading industrial centres of the world. We electrochemical engineers look upon Muscle Shoals as the new Niagara, the Niagara of the South.

What constitutes an electrochemical industrial centre? What are the essential requisites? What are the raw materials necessary for the production of that long list of metals, alloys, carbides, fertilizers, explosives, abrasives, lubricants, solvents, refractories, disinfectants, electrodes and gases for cutting and welding? The first essential is an abundant supply of cheap power—power to be had in large blocks for twenty-four hours a day and 365 days a year. Cheap power is almost always synonymous with water power—and of this the Appalachian South has been supplied by nature in gracious abundance. In the State of Tennessee alone, according to the estimates of Professor J. A. Switzer of the University of Tennessee, there are available almost one million horse power. In other words, Tennessee alone has enough power available to foster an electrochemical industry twice the size of that existing at Niagara Falls today. When our government decided to establish nitrogen fixation factories in this country and considered the various localities suitable for the electrochemical production of those most vital compounds, ammonia and nitrates—without which we could neither feed our populace nor defend our borders—our government, after due deliberation, most wisely decided to erect the "air saltpeter" factories at Muscle Shoals, Alabama. Therefore, as regards the supply of cheap water power

in the Appalachian South, there is no doubt. Careful surveys have reported a vast abundance. In this connection it is gratifying indeed to note that the United States Chamber of Commerce, composed of 500,000 business executives from every State and Territory in the country, a few weeks ago unanimously adopted resolutions calling on Congress to make provision for harnessing the millions in water horse-power that are now going to waste.

The development of our water power resources is of prime national economic value. It means the saving of coal and oil, which though most abundant here in the South are nevertheless exhaustible, and once used can never be replaced; it means the saving of railroad equipment now used for the transportation of coal and oil; it means the saving of a long list of valuable chemical products now burned and wasted under thousands of boilers; and it means the saving of millions of dollars in labor. The water power generated in the Province of Ontario, Canada, has reduced coal consumption between five and six million tons per annum. Under fairly efficient working conditions it requires from two to six pounds of coal to generate power equivalent to one horse-power-hour. Think of the tons and tons of coal represented by the available water horse power of this country, which is estimated by the Geological Survey at 32 millions, minimum potential.

The electrochemist looks upon the vast coal resources of the Appalachian South as intended for purposes of greater economic value. The coal reserves of a single State, West Virginia, have been calculated at 150 billion tons. The Southern coal makes the best coke, and when making coke very valuable by-products are conserved, which are lost when coal is burned under boilers. Alabama is the second largest coke producing State in the country. Tons of coke are shipped from the South to Niagara Falls and there heated in contact with sand in large electric furnaces that produce temperatures that are higher than can be attained in any other way. A beautiful crystalline product is obtained, carborundum, a silicon carbide, an abrasive which has found world-wide application. Another important electrochemical product largely dependent upon Appalachian coke is calcium carbide. This was first made by Willson at Spray, North Carolina, in 1891, by mixing ordinary limestone and coke and heating to very high temperatures in the electric furnace. Calcium carbide is the source of acetylene

which is used in conjunction with electrolytically produced oxygen in the oxy-acetylene torch for steel welding and steel cutting. You are all familiar with this time- and labor-saving device. Calcium carbide furthermore serves as the "raw material" in the manufacture of cyanamid, which the government will soon be turning out by the ton at Muscle Shoals. From cyanamid we obtain ammonia and this can be oxidized to nitric acid. Cyanamid is likewise a very efficient fertilizer. Another and very recent by-product of calcium carbide is acetone, which is consumed in large quantities in the manufacture of explosives. There seems to be no end to the list of electrochemical and chemical compounds and products of inestimable worth that are all primarily derived from Appalachian coke.

The South has been most strikingly favored by nature in the line of raw materials for electrochemical products. Next in importance to her coke resources are her extensive deposits of bauxite, the basic mineral from which that "metal of many uses," aluminum, is derived. The aluminum industry of this country ranks among the very first and consumes almost as much in kilowatts as all the other electrochemical industries put together. There are but four States in the whole country that have been mining bauxite in commercial quantities—Arkansas, Georgia, Alabama and Tennessee. In 1917 these States turned out 400,000 metric tons of bauxite, which is 12 percent more than the world's bauxite output of the year 1910. The Aluminum Company of America has erected a large metal-producing plant at Maryville, Tennessee. This appears to us as a very wise move. Why ship bauxite by freight hundreds of miles away? Why not make the metal near the source of the raw material? Why ship two tons of bauxite in place of one ton of aluminum metal?

Bauxite is also used for the manufacture of aloxite, alundum and exolon, artificial emeries of great hardness and uniformity, which are made in electric furnaces. The artificial abrasives, alundum, aloxite, carborundum and carbolon, have practically replaced imported emery and corundum. They have furthermore virtually revolutionized the machine shops, doubling and trebling their output.

The electrochemical industry which is most typically American is the electrolytic copper refining industry. Over 75 percent of

the copper consumed today is purified and refined by electrochemical methods. It is of the highest attainable quality, exceeding in purity most commercial metals. The largest electrolytic copper plant in the world is located at Canton, Maryland, with an annual production of 720 million pounds. The modern electrical industry with its dynamos and motors, its telephone, telegraph and wireless, and its countless electromagnetic devices would be hopelessly crippled if we were to deprive it of electrolytic copper.

In the electric steel industry the United States likewise leads the world. The quality of electric steel surpasses that of the best crucible steel. Next to Minnesota and Michigan, Alabama is the largest iron ore producing State in the Union. Over 50 percent of the iron ore reserves of the United States are located here in the South. Large electric steel furnaces are in operation at Chattanooga, Tennessee, and Anniston, Alabama.

Closely linked with the electric steel industry is the electric ferro-alloy industry—ferro-manganese, ferro-silicon, ferro-chromium, ferro-titanium and others. Ferro-silicon and other ferro-alloys are electrically made by the Southern Ferro-Alloys Co. at Chattanooga, Tennessee. Electric ferro-manganese is made by the Southern Manganese Corporation, Anniston, Alabama. Deposits of manganese occur in many parts of the United States, but are most abundant in the Appalachian and Piedmont regions, Virginia and Georgia being the largest producers, and Tennessee the best "quality" producer. Silicon is derived from quartz rock or sand. Titanium is derived from the mineral "rutile." For many years the sole producer of rutile in this country has been the American Rutile Company, whose plant is at Roseland, Virginia. Rails made of steel to which ferro-titanium is added during the process of manufacture, are less liable to breakage and are 40 percent more durable than are ordinary open-hearth rails. Another electric titanium alloy is cupro-titanium, containing 10 percent titanium and 90 percent copper. This is extensively used in making sound castings of copper and bronze.

Carbon bisulphide is a solvent upon which the rubber industry is very much dependent. Formerly it was made by tedious and expensive processes. Today all carbon bisulphide is made electrochemically. The raw materials are charcoal and sulphur. The

great sulphur States of the world are Louisiana and Texas. The combined output of these two States exceeds not only that of all other States put together but that of all the rest of the world. One of the many wells of the Union Sulphur Company discharges 500 tons of sulphur per day.

If we arrange the electrochemical industries according to the number of factories and the total power consumed, both in this country and abroad, we find that the electrolytic alkali and chlorine industry ranks fourth in the list. What a long array of interesting and important products have been developed and turned out by the ton by this industry—caustic soda and bleach, chlorine gas, sodium metal, disinfectants and peroxides and an endless series of valuable organic compounds. The basic raw material is common salt (NaCl), and it is interesting to note that Virginia is the sixth largest salt producing State in the country. To produce caustic alkali and chlorine the electrochemist takes this salt, dissolves it in water and passes a current of electricity through the solution. How simple is this electrolytic method compared to the old-fashioned process of producing alkali and chlorine, according to which you had to start out with pyrites or sulphur, oxidize this to sulphuric acid, add this acid to salt, thereby liberating hydrochloric acid; then taking this acid and treating it with manganese peroxide to "free" the chlorine gas; the sodium sulphate, obtained by adding the sulphuric acid to sodium chloride, was dried, mixed with coke and limestone and transformed by heat into calcium sulphide and sodium carbonate, finally the sodium carbonate was dissolved in water and boiled with lime, producing sodium hydrate or alkali. We certainly need not emphasize that electrolytic alkali spells "economy." Think merely of all the labor and energy that is conserved.

One of the most recent achievements of the electrochemist is the commercial production of electrolytic tin. Unfortunately, outside of Alaska, our country has no large tin deposits. The electrolytic tin refining plant at Perth Amboy derives practically all of its ore from Bolivia. However, during recent years our government has undertaken an earnest search for tin in this country and it is gratifying to read the recent report of the United States Geological Survey on promising deposits developed in the Kings Mountain and Lincolnton districts, North Carolina, and in Rockbridge

County, Virginia. According to this report it seems that if America is to have any tin industry at all it will be in the South.

Truly, nature has been most lavish with her treasures here in the Appalachian South! The electrochemical engineer finds in this region, so rich in natural resources, in water power, iron ore, coal, phosphates, manganese ore, alumina, titanium mineral, quartz, salt, copper, pyrites and limestone, the most ideal localities for the founding and fostering of important electrochemical centers.

An address delivered at the Thirty-third General Meeting of the American Electrochemical Society at Knoxville, Tenn., April 30, 1918.

THE PART THE UNITED STATES INDUSTRIES MUST PERFORM TO ENABLE THE ALLIES TO WIN THE WAR.

By C. G. Schluederberg.

In a recent patriotic speech, former President Taft, addressing 3,000 men and women at the Bellevue-Stratford Hotel in Philadelphia in the interest of the Third Liberty Loan, summed up in a few words the situation confronting the United States today, when, in paying a high tribute to the business men who are rallying to the cause of the country he said, "this is a business man's war and the genius of business must be mobilized for democracy."

In the early months of the war the majority of us, and even at this late day, entirely too many of us, have not as yet come to have a thorough appreciation of the tremendous part that the plain every-day business man has to play in establishing and maintaining our country on a war basis. We have perhaps been inclined to feel that the interests of the business man were entirely selfish—that he was interested only because he saw a chance for a large order carrying a good profit, and that such of those business men as had received commissions and taken up work for the Government at Washington and in the various other parts of the country in office and other non-fighting positions, were simply after the prestige and glory of an officer's uniform, while still retaining membership in the "safety first club."

However, after having had the opportunity of spending a considerable time in Washington endeavoring to co-ordinate one branch of a large manufacturing establishment with the requirements of the Army and Navy, and after being thrown in intimate daily contact with a great many business men of the country, who have given up lucrative positions and sacrificed considerable personal gain and who have absolutely put their personal affairs to one side and in many instances separated themselves from families for long periods of time, and come down to Washington under a

commission paying far less than their former salary and requiring the hardest kind of work from ten to sixteen hours per day, under anything but ideal conditions, I have come to have a far different and I might say a somewhat exalted opinion of the average every-day American business man. Personally it is my feeling that he has not received the credit justly due him.

He who, as an officer or private, takes his place on the firing line or in the trenches and who daily and hourly risks his life, manifestly deserves and receives the greatest honors; they are justly his, for he is playing the game with the highest possible stakes and justly claims the greatest reward.

The big captains of industry about whom we read almost daily in the headlines of the papers, who are putting aside their tremendous interests, many of which having engrossed their attention for almost a life-time may be considered as an integral part of themselves, and unselfishly devoting their tremendous energies, abilities and all their time to directing such important and vital government enterprises, as for instance, the Shipping Board, the Aircraft Board, the Ordnance Bureau, etc., without compensation and often at tremendous financial sacrifice, are also deserving of our highest esteem and honor.

But at this time it is to the average every day garden variety of business and professional man, who isn't a captain of industry and who hasn't a private fortune for his family to live on, that I wish to draw your especial attention. His number is legion and his importance to the United States and her Allies in the winning of this war is infinite. The majority of these men are being recruited from the office and minor executive forces of our large industrial corporations. They are taking up the work voluntarily, and the corporations are giving up their services willingly and cheerfully, knowing that their burdens will be shared by those who remain behind and that although much inconvenience and additional work will result, the government is benefiting thereby.

That the industries are giving the country thousands of their rank and file we know from the large service flags displayed on all sides, showing 500 for this company, 3000 for that company or 10,000 for another company, of employees in the service of the country.

From the daily papers we see such men as C. M. Schwab, chairman of the Bethlehem Steel Corporation, heading up the shipping program; J. D. Ryan, of the Anaconda Copper Company, heading up the Aircraft Board; H. P. Davidson, of J. P. Morgan & Company, heading up the Red Cross; Guy E. Tripp, Chairman of the Westinghouse Company, heading up the production work of the Ordnance Bureau, and so on. Almost every big captain of industry is unselfishly giving his entire time and energy to furthering the interests of the United States and her Allies.

So much for what the United States industries are doing in the way of giving their men to the service of the country.

Any of you who have read Edgar F. Smith's book giving an excellent history of early chemical and electrochemical research in America, cannot help but be impressed with the fact that although these sciences had a wonderful start in this country a century ago, their progress since then has been exceedingly slow. They were not properly fostered, nor did they receive deserved recognition. Previous to the war this was a source of grave concern to the better informed scientists and industrial leaders of the country, who saw what was being accomplished by those countries with whom we are now at war, who had the foresight to adopt many of the discoveries originating here and elsewhere, while our own industries held back and would not recognize the importance of research and its application to our own problems.

However, the war has brought home the importance of chemistry, electrochemistry and allied subjects to the American public, and these sciences are swiftly and surely coming into their own. It has gotten to be a common thing to find featured in the daily and even in the financial journals, headlines dealing with all sorts of chemical, electrochemical and metallurgical projects.

This war as a business man's war is a war of machines and science. The latest scientific developments are in constant use and a vast amount of scientific research is being carried on to make further discoveries to beat those already being applied by our adversaries.

The United States is now training over a million men to fight in France. Several million more will be trained. The industries of the country must furnish these men cannon, machine guns,

rifles, shells, powder, cartridges, gases, airplanes, automobile trucks, and all other equipment of war in enormous quantities.

To manufacture munitions high-grade alloy steel is necessary. For the preparation of the ferro-alloys used in making this steel existing electric furnaces are being worked to their utmost capacity. Numbers of new electric ferro-alloy furnaces are being constructed.

The vast quantities of abrasives which are so essential for the manufacture of machine guns, rifles, shells, automobile trucks, airplanes and all other machinery are almost all prepared in the electric furnace. In fact were it not for the electric furnace production of abrasives, it would be possible to produce only a small fraction of the vast amounts of machinery equipment for war purposes which are being turned out daily. The average man, unless he stops to consider the present manufacturing situation, has little or no conception of the fact that almost all fine machine work nowadays is finished with the use of abrasives.

For the manufacture of airplanes and auto trucks vast quantities of aluminum are required. This can only be manufactured by electrochemical processes. Large quantities of the zinc necessary in manufacturing the brass used in the millions of cartridge cases made daily are recovered from the ore and purified electrolytically.

Many of the gases used for war purposes, *i. e.*, hydrogen, chlorine, and bromine, are largely possible of preparation only by electrochemical means. Many of the nitrogen compounds used for preparing the vast quantities of explosives required by our army and navy will be prepared with the aid of electrochemical and electrothermal processes.

Other basic materials, such as magnesium, graphite, carbon electrodes, potassium chlorate, etc., which will be required in quantities, can only be prepared with the aid of the electric furnace or electrolytic cell.

It is self-evident to every thinking man that the chemical and electrochemical industries are essential to the winning of the war.

A recent issue of one of the leading financial journals made the statement that 60 percent of the steel production of the country was now being applied directly to war work. Conversation with some of the officials of the largest steel companies indicate that

this figure is a very conservative one, as the statement is frequently heard that many of the largest steel plants of the country are now almost 100 percent on war orders.

Manifestly the steel industry is the one industry in this country on which the greatest demands will be made by the United States and the Allies. It is of course the greatest of American industries. Its dependence on the electrochemical industry was very well brought out by Mr. F. J. Tone in a paper before the Electrochemical Society a year or more ago, in which he pointed out that of the 28,000,000 tons of finished steel products in the United States in 1915 a major portion was deoxidized by high-grade ferrosilicon, produced in the electric furnace, and that furthermore many of the specifications for shell steel for munition purposes, called for from 0.2 to 0.3 percent silicon; also that in the production of armor plate and armor-piercing projectiles, a very essential ingredient is ferro-chromium, which is strictly an electric furnace product. Without this alloy no battleships could be provided with armor, nor coast defense guns served with modern projectiles.

Considering some of the other ferro-alloys made in the electric furnace, such as tungsten, vanadium and molybdenum, it may be positively stated that they are absolutely necessary in the production of modern guns, machinery, machine tools, high-speed cutting tools and other devices which are in daily use in every machine shop throughout the country.

The manufacture of aluminum is one of the largest electrochemical industries in point of power consumed and value of product. Considering that without the aluminum industry it will be almost impossible to build airplanes and that the production of automobiles and trucks would be seriously handicapped, the importance of this industry is self-evident.

As pointed out in a recent article in the *Manufacturers Record,* were it not for the production of artificial abrasives in the electric furnace, such as carborundum and alundum, the machine shop would almost have to go out of existence, since practically every part of the machinery which is in movable contact with another part is subject to a finishing process requiring the use of a grinding wheel or abrasive in some form.

A partial list of the products and their application which the electrochemical and electrothermal industries of the country are furnishing at the present time, includes aluminum, with the use of which we are all so familiar; magnesium, used in making alloys of great strength and light weight, so necessary in aircraft, also for various devices used to illuminate battle-fields at night; carbon electrodes, used in all electric furnaces; the ferro-alloys—titanium, chromium, vanadium, silicon, molybdenum and tungsten, of such wide application in the steel industry, as pointed out above; nitric acid, which is of course one of the basic ingredients of all explosives; carbon bisulphide, extensively used as a solvent; sodium, used in various compounds and also in incendiary bombs; carborundum and alundum, used as abrasives; caustic soda, used by very many industries; chlorine, hydrogen, oxygen and other gases, all of wide military application; cyanamid, an important intermediate in the fixation of atmospheric nitrogen; phosphorus, used in the match industry and in incendiary bombs; caustic potash, sodium and potassium chlorate, used in the industries and in explosives; calcium carbide, used for the manufacture of acetylene and as an intermediate product in a number of important industries; graphite, used as a lubricant and also as electrodes in furnaces; electrolytic zinc and electrolytic copper of the greatest purity and of the widest possible application.

Practically every one of the above products is absolutely essential to the carrying on of the war and for their manufacture we are almost entirely dependent upon the electrochemical and electrothermal industries.

As a further example of what one of the big mining companies of this country is doing, we read in a recent issue of the *Wall Street Journal* that the Anaconda Copper Mining Company will shortly become one of the world's largest individual producers of ferro-manganese. This company is installing five electric furnaces in a disused part of its Great Falls plant, where surplus power now available from the hydro-electric developments of the Montana Power Company, will be applied to the manufacture of approximately 2,500 tons of ferro-manganese per month. As many of you know, this company today stands as one of the world's largest producers of copper, silver, and high-grade electrolytic zinc.

In a recent issue of one of the daily papers we find an advertisement by the National Aniline & Chemical Company, which has been recently organized by combining several of the largest existing chemical manufacturing companies in the country in order that the by-product of one may be properly utilized in the direct process of the other and in this way an organization built up, which will shortly outdistance the famous Badische Anilin & Soda Fabrik, which has been such a factor in supplying the Germans with war material, to the effect that they will exhibit at the Sixth National Textile Exposition, to be held in the Grand Central Palace, New York, from April 29th to May 11th, a display of over 50 colors, alongside of which will be shown similar colors of German manufacture, and all subjected to the most rigorous parallel tests to show that the American-made dyes equal those formerly bought elsewhere. This, we believe, is one of the best answers possible to those "calamity howlers" who a year or two ago were filling the press with statements to the effect that without the German dye industry the American textile mills would practically have to cease production.

One of the interesting points noted on this trip was the plant of the Federal Dye Works at Kingsport which, we understand, is equipped to turn out large quantities of dye stuffs.

We read elsewhere in one of the financial journals that this same National Aniline & Chemical Company has, after eighteen months of concentrated study, finally arrived at a method of producing a synthetic indigo in commercial quantities that is as good, if not better, than that usually bought overseas, and that they are constructing an addition to their plant at Marcus Hook, Pennsylvania, which will cost in the vicinity of one million dollars and which, when completed, will have a production that will care for at least half of this country's consumption. We are also advised that the DuPonts are going into the production of this dye on a large scale and that very shortly their plants, combined with those of the National Company, will furnish more than the total normal consumption of this blue dye for the country.

Another one of the most important industries of this country—the potash industry, which it was fully expected would amount to little or nothing during the war on account of scarcity of raw materials usually brought from abroad, is making very satisfactory

strides. The lakes of California, New Mexico, Utah and Nebraska, which give up a fair proportion of potash by a complicated evaporation process, are being worked, and many other possible sources of potash are being thoroughly investigated, and it is anticipated that these sources will yield approximately fifty thousand tons of the precious mineral during the current year. However, this is only a small proportion of the country's requirements and we therefore learn with considerable interest that it may be possible to obtain practically one-third of this country's requirements from the dust now being wasted in cement plants.

The Western Precipitation Company, using the Cottrell process of electric precipitation has, after many experiments, perfected a method by which it is hoped to utilize all waste dust of the Portland Cement plants for the recovery of potash, thereby not only helping out the supply of the country, but returning to the cement plants a very fair profit.

The Cement Works at Kingsport recently inspected on this trip is one of the plants which is using the Cottrell process to save the dust containing a large percentage of potash, which was formerly allowed to go to waste.

Considering further the electrochemical and electrothermal industries, we all remember that a few years ago the electric furnace as applied to the manufacture of high-grade steel was considered little more than an interesting experiment, and when anyone mentioned to the old steel makers the possibility of the electric furnace supplanting the crucible process he was laughed at and treated with scorn, but within the last three years the number of electric furnaces applied to the manufacture of high-grade steel has increased so tremendously that today it is a question as to whether the best crucible steel manufactured by the former process can in any way compete with electric steel. The expensive experiments of ten years ago, today form an indispensable equipment of every modern steel plant. A number of steel casting companies as well as large manufacturing companies, as for instance the Timken Company, which turns out enormous quantities of axles and bearings for automobiles, use electric furnaces exclusively.

Of especial interest to the country just now is the impulse given to the chemical and electrochemical industry by an appropriation

by the Government of fifty-five million dollars for the establishment of a synthetic nitrate and ammonia plant at Muscle Shoals.

Previous to the war almost all our high-grade optical glass had to be obtained from Germany. We are now advised by the representatives of some of the largest glass manufacturers, one of whom is, I am proud to say, located in my home city, Pittsburgh, that the optical glass problem has been solved by American chemists, and that a grade entirely satisfactory for all the most exacting requirements is being turned out in increasingly large quantities, and that we need have no further concern or worry on this subject.

We all realize the immense importance of the automobile truck industry and the rubber tire industry to the maintenance and success of our armies. It is a matter of common knowledge that these industries are fully meeting the immense demands that are being made on them.

The foregoing review covers but briefly a few of the industries of the country and their application to war work and it would not be possible to conclude this review without emphasizing what must be apparent to everyone here and that is that all of these industries are intimately connected with one of our most important public utilities, that is, the central stations. Without vast quantities of central station power at reasonable rates it would be impossible for any of the electrochemical industries to exist. The problems of the central station, many of these of the electrochemical and electrothermal industries, are largely one and the same thing. The time has come when one cannot go along without the other; their interests are identical and practically the same may be said for the transportation companies; raw materials and finished products must be transported.

Illustrative of the fact that these general problems are recognized by our highest executive I quote part of an address by President Wilson at Washington, D. C., to the American Electric Railway Association, in which he clearly points out the dependency of our Government on the industries and the necessity of maintaining these in a high state of efficiency:

"A just price, of course, must be paid for everything the Government buys. By a just price I mean a price that will sustain the industries concerned in a high state of efficiency, provide a living for those who conduct them, enable them to pay good wages,

and make possible the expansion of their enterprise which will from time to time become necessary as the stupendous undertakings of this great war develop. We could not wisely or reasonably pay less than such prices. They are necessary for the maintenance and development of industry, and this maintenance and development are necessary for the great task we have in hand."

In conclusion of this brief review, I think it can be safely said that in this war the United States and her Allies are absolutely dependent on the industries of the country, not only for contribution of men to make up the rank and file of the army, but for responsibility of seeing to it that our fighters are properly supplied with the necessities of war so that their energies and abilities may be properly co-ordinated and supported by machine guns, supplies and the munitions of war of all kinds, for without these products of the industries, their lives would be needlessly sacrificed and our chances of winning the war small.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Chattanooga, Tenn., May 1, 1918.

THE CHEMICAL, ELECTROCHEMICAL AND METALLURGICAL RESOURCES OF THE CHATTANOOGA DISTRICT.

By T. P. Maynard.[1]

The vast potential chemical, electrochemical and metallurgical resources of the South are, as you are well aware, rapidly becoming kinetic.

Picture, if you will, Chattanooga in the center of a district where of the 53 commercial minerals produced in the United States at least 48 are available. Chattanooga lies within 60 miles (96 km.) of the largest sulphuric acid plant in the world, in which during the past year there was a daily production of approximately 1,000 tons. At this same point is located the largest producer of copper east of the Rockies. In the next few years the largest output of aluminum in the world will be produced in Tennessee and North Carolina. At a point about 150 miles (240 km.) west of Chattanooga is located the largest phosphate field, with the exception of Florida, in the United States east of the Rockies. One hundred miles (160 km.) to the South, in Georgia, is located the largest producer of barytes, and also large deposits are being developed about 75 miles (120 km.) to the northeast. Acid brick are being manufactured within a few miles of the city at the only plant of its kind in the South. The cement resources of this district are limitless, and the relation of these materials to fuel, power, transportation and market is indicative of its great future growth. Limestone of the purest quality is located in immediate proximity and is suited for the manufacture of chemical products. Millions of tons of coal, and coking coal of the highest quality, are found in this district, and Chattanooga lies at a point near the center of the coal area of Tennessee. Iron ore is found in the immediate district, and brown and manganiferous ores are found in Tennessee, Georgia and Alabama. Bauxite

[1] Geological and Industrial Engineer, Atlanta, Ga.

is confined entirely to the South, and there is no place so situated as is Chattanooga with regard to the transportation of bauxite from the four principal Southern fields, namely, Tennessee, Alabama, Arkansas and Georgia. The largest deposits of manganese and manganiferous iron in the East are confined to Georgia, Alabama, Tennessee, Virginia and Arkansas. Clays of every description are now being utilized by chemical industries in the North and East and are being shipped from this area in Tennessee and Georgia, particularly for the manufacture of refractories and allied chemical industries. The large zinc deposits of the Knoxville district are rapidly being developed, and these deposits are found at a point about 130 miles (200 km.) northeast of Chattanooga. The salt deposits which are found near the Tennessee-Virginia line are at a distance of only 260 miles (400 km.). Georgia ranks second in the production of marble, and Tennessee, third, and the by-products which are available for chemical industries should make possible their development where cheap raw materials are to be taken into consideration. The largest deposits of ocher in the United States are developed at a point about 150 miles south of Chattanooga, in the Cartersville district of Georgia. Among the other materials which are found in large quantity are pyrites, quartz, sand, slate, soapstone, tripoli, asbestos, whiting, dolomite, feldspar, mica, and mineral paint. Graphite so essential for use in lubricants and the manufacture of crucibles, is found in Alabama, where the largest known deposits in this country exist. Fuller's earth for use in the refining of oils is being largely developed in Georgia and Florida, and gypsum is found near the Tennessee line in Virginia.

The largest hydro-electric developments in Tennessee are now confined to the area known as the Chattanooga District, while the new Niagara of the South, where 600,000 horsepower will be available, is rapidly under way.

Mr. Washburn has told you, "In 1914 the farmers east of the Mississippi purchased $75,000,000 in value of nitrogen products and an equal amount of phosphoric acid. During the period from 1900-1910 the population of the United States increased 21 per cent., while the crop production increased 10 per cent. It is very evident that one of the problems most vital to the development of the nation is that of increasing crop production without addi-

tional labor." Dr. Baekeland has said: "You may be well aware that before the war Belgium used more nitrogen fertilizers than Germany and that the yield per acre in Belgium, especially in Flanders, was considerably higher than the yield per acre of any other country." You may naturally wonder why Chattanooga is so located with relation to all of the varieties of mineral products, and I am not sure that this relation has previously been explained.

The geology of the southern United States is such that in traversing the area from the east coast of Georgia to the Mississippi River transversely, a greater number of geologic and physiographic provinces are traversed than in any other section of the United States. In such a great variety of rocks necessarily conditions are favorable for the presence of a wide variety of minerals and the intimate intersection of this area by streams, many of which are navigable, has made possible a topographic condition where both water and rail transportation make accessible the assemblage of raw materials not only from a direction northwest and southeast, but also northeast and southwest. Six geologic and physiographic provinces occupy this territory—the Coastal Plain, the Piedmont Plateau, the Appalachian Mountains, the Appalachian Valley, the Cumberland Plateau, and the plains which extend to the Mississippi.

The possibilities of electrochemical and allied industries are almost beyond our conception. The relation of the large varieties of clays which are now largely shipped to the North and East, together with the markets which are already developed and which promise to be of such extent, bring out the importance of the manufacture of high-grade refractories in which the South is at present lacking. A larger development of vitreous chemical ware, the manufacture of electrical porcelain and the manufacture of white ware pottery, of which more than $12,000,000 in value is annually consumed in the South, should be promoted. The manufacture of the ferro-alloys, ferro-silicon, ferro-manganese, ferro-titanium, ferro-phosphorus, offers a splendid field, for while the present demand is very great, the future development of industries such as the automobile and aeroplane will create a very much larger demand after the war. Abrasives are dependent upon coal and coke, clays, and bauxites and silica.

Many of these materials are now being shipped to Canada, where so many of our abrasive industries have located on account of the availability of power. The manufacture of calcium carbide, which is a source of acetylene and from which is manufactured acetone and acetic acid, is another possibility, particularly so on account of the relation of hydro-electric power to the enormous deposits of high-grade limestones.

We seem to have forgotten in the midst of our great chemical and electrochemical development the one material which will mean as much as any other for the permanent establishment of peace and the freedom of the world from German dominance of our essential foods. This element is necessary in the formation of starch, the sugar and sap for grains and fruits. We are certainly now affected in the development of many of our industries and the development of our agriculture by its almost complete isolation. The trump card of Germany when peace terms are made will be the control of that element, potash, which we are absolutely dependent upon for our future existence. In 1914 potash salts were imported from Germany at a value of approximately $15,000,000. Only about 20 per cent. of our pre-war needs are now being produced from our limited Western salts and as by-products in the manufacture of Portland cement through electrical precipitation by the Cottrell process.

In Georgia there are sericites and potash-bearing slates carrying eight to ten per cent. potash, with a high content of alumina and combined water. In an effort by chemical methods to make water-soluble and available this potash it has been found that it was difficult to keep the potash from volatilizing, so that what appeared as the most objectionable feature is now the most desirable, for with the perfection of the electrical precipitation of the dust it is possible to recover about 70 per cent. of the potash values. You can realize, gentlemen, what this would mean under present-day values and the utilization of the slag, and when both phases of the development are carried out on a large scale it will mean profitable development under post-war conditions.

These deposits are located directly on railway transportation. They extend for miles of uniform thickness and of great depth. They are simple open-cut mining propositions. It is the relationship of combined water and thickness and accessibility of depos-

its together with the relationship of the accessory elements that combine to make Georgia the future center of potash production. I want you gentlemen to think what this means in its relation to chemical and electrochemical development. Think of the allied industries which will spring up.

Picture Chattanooga within easy reach of the vast hydro-electric power which will be developed at Muscle Shoals, her position with relation to the two most important acids used in the chemical industry; sulphuric acid on the east and nitric acid on the west. Picture your industries in the center of the Tennessee coal fields where more than two-thirds of the commercial minerals mined in this country can be assembled at a small cost. You will realize also that the Tennessee River is an important factor in your transportation.

I believe that the forces of attraction which have brought us together will be cemented by bonds of friendship which will assure co-operation for the great development of electrochemical industries upon which the nation is so dependent.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Chattanooga, Tenn., May 1, 1918.

THE COAL AND IRON RESOURCES OF THE CHATTANOOGA DISTRICT.

By E. M. Jones.[1]

COAL.

The Coal of this district is of the carboniferous age, which here is composed of the Bangor limestone at the base and the Lookout and Walden formations, containing the coal seams, above.

The coal seams are ten or more in number distributed through about 1,000 feet of the Lookout and Walden formations. The high point a mile or so northwest of this beautiful inn, across the gulf of Middle Creek, and which has an elevation of 2,000 feet above sea level, contains number 10 seam.

All the seams are quite variable in thickness, the Sewanee seam being the least so, but are fairly constant in quality. The average thickness may be set at 24 inches to 30 inches (60 to 75 cm.). This applies to the coal seams within 75 miles (120 km.) of Chattanooga. To extend the distance to 150 miles (240 km.) would be to take in a much more varied quality of coal and thicker seams. Within the larger distance the quality will vary from 45 to 20 per cent. of volatile matter, and from 47 to 75 per cent. of fixed carbon.

Half a million tons per year are now produced, inside a freight rate of 45 cents per short ton; 5,000,000 tons are produced within a 90-cent rate.

The principal seam mined is the Sewanee, which is mined in both Walden Ridge (which is the plateau on which we are now) and Cumberland plateau. In the two plateaus there may be as much as a billion tons of Sewanee coal. The quality is very like the famous Connellsville coal of the Pittsburgh, Pa., region, and with the same careful treatment will make as good a coke. Its

[1] Mining Engineer, Chattanooga, Tenn.

composition or analysis is: Fixed carbon, 57 to 63; volatile matter, 27 to 32; ash, 7 to 10; sulphur, 0.60 to 1, and phosphorus, 0.05 to 0.10. Over 90 per cent. of the coke made in the district is made from this coal.

Estimating the tonnage on the basis that under the four plateaus, namely, Walden Ridge, Cumberland Mountain, Lookout Mountain and Sand Mountain, there is one seam of coal 30 inches thick, there are 4,000,000,000 tons of coal within 75 miles of Chattanooga. In normal times Chattanooga can purchase good steam coal for not over $2.25 per short ton.

COKE.

There are about 2,500 beehive coke ovens now being operated within 75 miles of Chattanooga, and one plant of 24 ovens of the Semet-Solvay type in the city. These by-product ovens were built last winter and they hold about 16 tons of coal and make about 74 per cent. of the coal into a high-grade coke. The beehive ovens make 52 per cent. of the coal into coke.

The yield of surplus gas from one ton of coal is 5,000 cu. ft. (140 cu. meters); the B. T. U. of the gas is 597; the yield of tar is about 8 gallons (45 kg.); of sulphate of ammonia, 22 lb. (10 kg.); of light oil, 2 gals. The coke carries about the same percentage of sulphur that the coal contains.

IRON ORE.

Mr. Burchard, of the United States Geological Survey, said in the Engineering and Mining Journal of Sept., 1909: "For my part, I think it makes the Chattanooga district compare very favorably with the other districts of the South. The reserves of ore that will be available for future use are shown to be larger than those of the Birmingham district, judged by the same standards."

There are three varieties of iron ores in the district: brown hematite, Clinton red hematite, and magnetite.

The quantity of brown hematite can be nothing but a guess, and I guess 30,000,000 tons. It is mostly in residual deposits and will yield, as shipped to the blast furnaces, about 47 per cent. metallic iron.

The quantity of magnetite is quite uncertain; it may be many millions of tons, but it is of interest because of its low phosphorus content, which is 0.009 per cent.

The Clinton red hematite is here in vast quantities. It is in the rocks of the Silurian era and is the same ore as the Belgium, German, Lorraine, Luxemburg and Poland ores. It lies like coal in beds or seams, and here there are usually three beds, the bottom one being the thickest and most productive. It will average, where prospected, under Walden Ridge, Lookout Mountain and Sand Mountain from 30 inches to 36 inches thick, with generally a small parting of an inch, sometimes 6 inches where the bed is thick.

The quality of the hard ore varies between 25 to 40 per cent. metallic iron; 20 to 50 carbonate of lime; 5 to 20 silica and alumina; from a trace to 1 of sulphur; from nothing to 1.6 of manganese, and 0.3 to 0.7 of phosphorus.

The ore beds underlie the four plateaus in troughs irregularly inclined at the edges; the syncline being 200 feet or so below the general level of the valleys at the foot or base of the plateaus. The area covered is, therefore, very large, and if we assume one bed is workable at 30 inches thick and that 50 per cent. of the above area contains one such bed, then the Chattanooga district has within 75 miles of it as much as 4,000,000,000 to 5,000,000,000 tons of this red hematite ore.

There is about 700 feet of limestone between the iron ore and the coal; all three materials for making pig iron can be taken from the one mine.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

THE MINERAL RESOURCES OF ALABAMA.

By Eugene A. Smith.[1]

Abstract.

The following is the report of an oral presentation of the most important mineral resources of Alabama, before the meeting of the Society in Birmingham, Ala. Dr. Smith prefaced his remarks by saying that the statistics of mineral production of Alabama were for the year 1916, since the full returns for 1917 had not yet been received and tabulated. His remarks were illustrated by a large geological map of the State, and by a statistical chart here reproduced.

Coal represented in 1916 a value of nearly twenty-five million dollars. Part of that coal was converted into coke valued at sixteen million dollars and a little over, and there are by-products which are not enumerated. But in the conversion of the coal into coke and its by-products, probably the value is trebled.

Iron Ore is our next great resource. The red ore, which occurs in the "Red Mountains" of the anticlinal valleys, is found normally on both sides, but on one side only is the ore of any particular consequence; on the other side the ore stands vertical and is cut out a great deal by faults, so that there is always along these valleys, theoretically, two red mountains, one on the east and the other on the west, but as a matter of fact the productive mountain is confined generally to the eastern side, except in Murphree's Valley, where it is on the west; that is on account of a little difference in the wrinkling or folding of this territory. The brown ores occur in the residual clays overlying the paleozoic limestones. Iron ore represents a value of $10,840,000. The pig iron made therefrom represents a value of nearly $39,000,000.

[1] State Geologist, University of Alabama.

Limestone has a variety of uses. In the first place it may be used raw for building stone and for furnace flux, and it may be ground up for fertilizer and similar products, representing the combined value of about $1,180,000, of which the limestone of the Tennessee Valley and the marble of Talladega used for building purposes, have a value around a quarter of a million dollars. The fine quality and great durability of the limestone and the surpassing beauty of the marble can here receive only bare mention. The principal products derived from the limestone are cement and lime. The Portland and slag cement of Alabama represented in 1916 about one and a half million dollars, and the limestone converted into lime yielded a product valued at about $312,000.

Clay is one of our most important but practically undeveloped resources. I am at a loss every time I think of the matter to explain why it is that Alabama with such a tremendous wealth of kaolin, china clays, and all other varieties of clays, has done practically nothing with them, since the small valuation shown on the chart, one million and a half, would not be counted anything in some of the other States, like New Jersey and Ohio. Clay may be considered under two heads, *viz.,* the raw clay, which is mined and sold without being converted into anything else representing a value of about $51,000, and the clay products, including on the one hand the many varieties of brick, and on the other hand the tiles, sewer pipe and pottery, representing something more than a million and a half dollars.

Graphite is another of our mineral resources which is coming to the front, and which will some of these days be worth talking about. A few years ago we had a production of only a million pounds, or something like that. At the present time there are 24 companies working on graphite, and the production in 1916 was valued at nearly half a million dollars. In 1917 it will be considerably more than that, and this year, 1918, it will be still greater, since the production is constantly increasing.

Sand and Gravel production represented the moderate sum of $187,000.

Bauxite, the oxide of aluminum, and the material out of which many products are made, including the metal aluminum, had a

high value, but as there was only one producer in Alabama, the production cannot be revealed, but it is over $27,000.

Pyrites mining is a comparatively new industry, which has received a great stimulus by reason of war needs.

Sandstone production was valued at about $21,000, and was used partly as building stone, but mainly as a refractory (ganister) and in electro-metallurgical processes. The supply of high-grade silica rock in northeastern Alabama is practically unlimited.

Mineral waters were valued at $12,174.

Gold is practically not in it; we have only four or five mines or placers producing gold, with an annual value of $8,000 only.

Natural gas is a new thing with us. We have two or three fields where small amounts of gas have been obtained, *i. e.*, in the Tennessee Valley, in the neighborhood of Fayette Court House, near Jasper in Walker County, and of late in the Cahaba coal field, a few miles east of Birmingham a number of wells have brought in a sufficient amount of gas to make it probable that there will very soon be a notable supply for industrial purposes here in Birmingham.

Mica is another mineral the mining of which is capable of great expansion, but there is at the present time very little production.

Manganese: There is at this time a great demand for manganese for war purposes. We have not as yet any figures showing the production of manganese in Alabama, but in most of our valley regions, especially in Murphree's Valley, and along the western border of the crystalline schists, there are outcrops of manganese ore that are exceedingly promising and worthy of further investigation.

Lead likewise has been found in the valley regions where the prevailing rocks are limestones. In Calhoun County a lead mine was worked during the Civil War by the Confederate Government. Since that time the mine has been idle, probably because of limited quantity of ore and lack of adequate concentrating apparatus. Of late years another source of lead has been found in Cherokee County near Jamestown, so that lead production is again a possibility.

Tin Ore has been found in quite a number of localities. In Coosa County, particularly, lumps of crystalline tin ore, two or three inches in diameter, indicating a vein of considerable size, have been collected. Strange to say, though, with all the search we have been able to make we find nothing but this scattered tin ore on the surface; the vein has never yet been discovered. What the result will be no one can tell, but it is certainly something worth

Mineral Production of Alabama—1916.

Figures Subject to Revision

	Raw	Derived
Coal	$24,859,831	.....
Coke	.....	$13,019,139
Iron Ore	10,843,231	.....
Pig Iron	.....	38,994,660
Limestone (Flux, etc.)	1,180,800	.....
Cement	.....	1,410,104
Lime	.....	312,531
Clay	51,053	.....
Clay Products	.....	1,520,301
Graphite	492,407	.....
Sand and Gravel	184,216	.....
Bauxite	*	.....
Barytes	27,198	.....
Sandstone	20,995	.....
Mineral Waters	12,174	.....
Gold	8,650	.....
Natural Gas	*	.....
Mica	5,615	.....
Miscellaneous	42,966	.....
	$37,729,136	$55,256,735
Total	.....	$92,985,871

* Included in Miscellaneous.

investigation, since in the United States only four or five States have produced any tin at all, viz., South Dakota, Virginia, North Carolina, South Carolina and Alabama. This production, however, is comparatively insignificant, and it behooves us all to be on the lookout for tin ore, since the tin from other countries may be cut off completely, and we may have to rely upon tin of our own production.

Petroleum: While hundreds of wells have been put down in Alabama in search of petroleum, there have been as yet no pro-

ductive wells, properly speaking. In the Tennessee Valley occurrences have been known since the day of Prof. Tuomey, of tar springs, and naphtha springs, of bituminous sandstone and bituminous limestone, but borings there have not yet brought in, in any notable quantity, the oil indicated by these phenomena. The same may be said concerning borings in other parts of our Paleozoic area; promising looking oil sands have been brought up, and in several places small quantities of oil, to be measured by a few barrels, but nothing of commercial importance. In our Coastal Plain region, where petroleum is found in Louisiana and Texas, we have not yet struck it, notwithstanding numerous borings. Gas has been obtained, but so far as I know no oil, or at most only oil-saturated sands.

DISCUSSION.

F. J. Tone[1]: I would like to ask Dr. Smith if the graphite produced is suitable for crucibles.

Dr. Smith: Yes, sir; as the result of experiments made with the Alabama graphite by the Crucible Steel Co. of Pittsburgh, Pa., that company is credited with the following statement: "A good crucible can be made with all Alabama graphite, and the company would be willing so to modify their mixture as to adopt its use exclusively if a sufficient quantity of their desired quality could be assured." More recently the U. S. Bureau of Mines has undertaken an exhaustive examination of the Alabama graphite with reference to its suitability for the manufacture of crucibles.

[1] Works Manager, The Carborundum Company, Niagara Falls.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918, President Fink in the Chair.

THE SIGN OF THE ZINC ELECTRODE.[1]

By Wilder D. Bancroft.[2]

The German physical chemists have changed their position several times as to the sign to be applied to the zinc electrode. In 1887 Ostwald[3] used the minus sign. "Zinc and cadmium are negative in all the acids tried, and copper, antimony, bismuth, mercury and silver are positive in all, while tin, lead, and iron show positive and negative values of 0.1-0.2 volt. The average potential for zinc is — 0.7 volt; for cadmium — 0.3; for tin, lead, and iron, ± 0; for copper + 0.3-0.4; for bismuth + 0.4; for antimony + 0.3; for silver + 0.5; and for mercury + 0.8." Ostwald takes the potential of the solution as zero, p. 600.

In 1893 Ostwald[4] uses the plus sign with zinc, probably because Nernst had developed the idea of solution pressure and zinc had a positive vapor pressure. "The values in volts for the single potentials of a number of the more important metals in solutions containing one gram-atom of the metal per liter are: Mg, + 1.22; Zn, + 0.51; Al, + 0.22, Cd, — 0.19; Fe, — 0.06; Pb, — 0.10; Cu, — 0.60; Hg, — 0.99; Ag, — 1.01. The values are given from the metal to the electrolyte, the potential of the metal being called zero. The plus sign with zinc denotes that the electrolyte is charged positively with respect to zinc. If one counted from the electrolyte to the metal, one would call the zinc potential negative."

LeBlanc[5] adopts the same point of view in 1896. "We will call the potential of the metal or the electrode zero, in which case the plus or minus sign shows whether the electrolyte is positive or negative with respect to the electrode. We must therefore say

[1] Manuscript received March 11, 1918.
[2] Professor of Physical Chemistry, Cornell University.
[3] Zeit. phys. Chem., 1, 604 (1887).
[4] Lehrbuch allgem. Chemie, 2 II, 946 (1893).
[5] Lehrbuch der Elektrochemie, 177 (1896).

Hg | Hg_2Cl_2 in N/1 KCl = 0.56 volts, and Zn | N/1 $ZnSO_4$ = + 0.52 volts." In 1900 Nernst[6], Wilsmore[7] and Ostwald[8] all use a plus sign with the zinc electrode and a minus one with the calomel electrode. Another change was foreshadowed in 1905, when Luther[9] wrote "I consider it very advisable to put a plus sign before the potential difference when the electrode in question is positive to the zero electrode, whether that be the calomel electrode, the hypothetical flowing electrode, or the extrapolated hydrogen electrode."

None of the books now accessible show when the Bunsen Society adopted this suggestion; but in 1915 Foerster[10] writes: "To show the direction of the electrical polarity between metal and solution we place before the value of the difference of the two potentials, the so-called potential of the metal, the sign of the charge on the metal. When dipped in solutions of their own simple salts or of acids, the readily oxidizable metals such as Al, Mg, Mn, Zn, Cd, Tl, Fe, acquire a negative potential, while the less readily oxidized, or noble metals, such as Cu, Hg, Ag, acquire a positive charge.[11] Volta arranged his first cell, Cu, Zn, H_2SO_4, Cu, Zn, and consequently the copper carried off the negative charges and the zinc the positive charges. Because of this, Berzelius called the readily oxidized metals electro-positive. This nomenclature remained unchanged even though the error of Volta's arrangement was soon corrected. In consequence, for a long time—and also in the first edition of this book—the sign of the potential of the solution was made the same as the charge on the solution, and the potential of the zinc was therefore called positive.[12] Especially for students, the difficulties were so great in a point of view whereby the negative current flowed from a positive electrode, that it became necessary to adopt the recommendation of the Bunsen Society to denote the potential in accordance with the charge on the electrode."

All the Germans now use the minus sign for the potential of zinc in zinc sulphate solution, and so do the English. In this

[6] Zeit. Elektrochemie, **7**, 254 (1900).
[7] Zeit. phys. Chem., **35**, 291 (1900).
[8] *Ibid*, **35**, 333 (1900).
[9] Zeit. Elektrochemie, **11**, 780 (1905).
[10] Elektrochemie der wässrigen Lösungen, 125 (1915).
[11] The rest of this paragraph is a foot-note in the original, but that seems unnecessary here. W. D. B.
[12] Foerster has overlooked Ostwald's position in 1887. W. D. B.

country the practice is by no means uniform, as may be seen from the rather acrimonious discussion[13] at Detroit.

Lewis [14] came out strongly some years ago in favor of using the plus sign for the zinc electrode. "On account of the importance in free energy calculations of those chemical reactions which occur in a voltaic cell during the passage of a current, it is very desirable that suitable conventions be adopted for the sign of an electromotive force, or of a single potential difference. It is not sufficient to state that a cell composed of cadmium amalgam, saturated cadmium sulphate solution, mercurous sulphate, and mercury gives an electromotive force of 1.0183 volts at 20°; for, a person unacquainted with the cadmium cell would not know whether the cell would do work through the consumption of cadmium and the deposition of mercury, or *vice versa*. We may, however, in this as in other cases, eliminate any ambiguity by writing the chemical equation, Cd (12.5 percent amalg.) + $Hg_2SO_4(s)$ + $8/3H_2O$) (saturated with $CdSO_4$ $8/3H_2O$) = Cd SO_4 $8/3$ $H_2O(s)$ + $2Hg(1)$, and now if we say that at 20° the E. M. F. is 1.0183 volts, the positive sign will indicate that the cell is capable of doing work when the reaction runs from left to right. So also we write for the reaction $1/2$ $Hg(g)$ + $1/2$ $Cl_2(g)$ — HCl (0.1M); E = + 1.4881 at 25°, meaning that work is done by a cell in which hydrogen and chlorine combine to form hydrochloric acid in 0.1M solution. Instead of writing the chemical reaction in such a case, we may express the same facts in another way, which shows better the actual construction of the cell in question. The form $H_2(g)$, HCl(0.1M), $Cl_2(g)$; E = + 1.4881 expresses the same facts. In such an expression *the positive E. M. F. indicates the tendency of the positive current to run through the given cell from left to right.* . . .

"The committee of the Bunsen Gesellschaft has adopted two symbols E_c and E_h for electrode potentials measured against the two standards, the normal calomel electrode and the normal hydrogen electrode. The potentials, as given in the following papers, based upon the standard above defined, are approximately equal to E_h except for sign. The Bunsen Gesellschaft makes the

[13] Trans. Am. Electrochem. Soc., **31**, 249-255 (1917).
[14] Jour. Am. Chem. Soc., **35**, 1, 25 (1913).

potential of sodium negative, and that of chlorine positive. I have adopted the opposite sign in conformity with the older and more common usage. Exactly what the committee means by the normal hydrogen electrode they have not stated. The potential of hydrogen against a normal solution of hydrochloric or of sulphuric acid, is a perfectly definite thing, but the potential of hydrogen against a solution normal in hydrogen ion must depend upon some assumption regarding the degree of dissociation, and different views will lead to values differing by 5 or 10 millivolts."

We are all agreed that electricity tends to flow from a place of higher potential to a place of lower potential; but that is not sufficient to enable us to settle the problem. In the Daniell cell the so-called positive current flows from the copper to the zinc outside the cell, from which we may deduce that the potential of copper is higher than zinc. On the other hand, the positive current flows from zinc to copper inside the cell, from which we may deduce that the potential of zinc is higher than that of copper, and we are no further ahead than before. The physicists have been interested in the current outside the cell and consequently they call the copper pole the positive one. The engineers have followed the lead of the physicists and call the positive pole of the dynamo the one where the positive current comes out of the machine. This brings the dynamo and the primary cell into line when considered as sources of electrical energy. It is also the point of view adopted officially by the Bunsen Society, and unofficially by the English electrochemists. It is apparently the only point of view which can possibly be adopted universally. On the other hand, it is one that is repugnant to chemists at first sight. Zinc precipitates copper from a copper sulphate solution, and therefore has a higher potential than copper. This is the side of the problem which appeals to Lewis, for instance. He knows that the free energy of zinc is greater than that of copper. I sympathize fully with Lewis' point of view, and if there were no way out of the dilemma I should be inclined to break with the physicists rather than to sacrifice a fundamental tenet of chemistry.

As I see it now, the difficulty is not a real one. We know that the electromotive force of a reversible cell is a measure of the chemical potential, or chemical affinity, and I have made the mis-

take in the past of assuming that since the values were the same the signs must also be. The whole difficulty disappears if we say that the chemical potential of zinc in the Daniell cell is higher than that of copper, while the electrical potential of copper is higher than that of zinc. When a piece of zinc is dipped into a zinc sulphate solution, some zinc goes into solution as ion, charging the solution positively and leaving the zinc charged negatively. A positive current tends to flow from the solution, the place of higher electrical potential, to the zinc, the place of lower electrical potential; but no current does flow because the electrical potential from the solution to the metal is balanced by the chemical potential from the metal to the solution. If we dip a piece of copper into a copper sulphate solution, we usually consider that some copper ions are precipitated on the copper charging the copper positively, and leaving the solution charged negatively. No current flows after the charging current because, by hypothesis, the positive electrical potential difference from metal to solution is balanced by the chemical potential difference from the copper sulphate to the copper. When the zinc and copper electrodes are joined metallically, a current flows from the copper to the zinc and the chemical reaction regenerates the electrical potential difference continually. Neglecting a possible potential difference between the zinc sulphate and copper sulphate solutions, the electrical potential in a Daniell cell on closed circuit drops from the zinc sulphate solution next the zinc electrode to the copper sulphate solution at the copper electrode. Here it is pumped up by the chemical energy, if the copper is positive to the solution on open circuit. From the copper electrode the electrical potential drops through the metallic circuit to the zinc electrode, which is the place of lowest electrical potential in the whole circuit. Here the chemical energy of the zinc pumps up the electrical potential to the old level, and so forth. While the zinc electrode is always the place of lowest electrical potential in the circuit, the place of highest electrical potential will vary with the conditions under which the cell is operating. If the internal resistance is low and the external resistance is high, the drop of electrical potential through the solutions will be less than the rise of potential at the copper electrode, and consequently the copper electrode will be the point of highest electrical potential in the

system. The limiting case is of course when the cell is on open circuit. If the internal resistance is very large and the external resistance practically negligible, the place of highest electrical potential will be the zinc sulphate solution in immediate contact with the zinc electrode, because the drop of potential through the solution is greater than the rise of potential at the copper electrode. If we have a cell of the Daniell type, Zn | $ZnSO_4$ | $CdSO_4$ | Cd, where cadmium is also charged negatively, and the solution positively by definition, there will be a fall of electrical potential when passing from the cadmium sulphate solution to the cadmium electrode, and consequently the place of highest electrical potential will always be in the zinc sulphate solution right next the zinc electrode, though the drop of potential from here to the cadmium sulphate solution in contact with the cadmium electrode will be practically zero when the cell is on open circuit.

When the electrodes form positive ions the metal with the higher chemical potential, or the greater free energy, becomes the anode. With electrodes which form anions, the reverse will of course be true and the substance with the greater free energy will form the cathode. Bromine sets free iodine from iodide solutions, and therefore has the greater free energy. In a cell with iodine and bromine electrodes, the bromine electrode is the cathode. It is interesting to note that this whole argument was given in a very condensed form by Gibbs.[15] "When all the conditions of equilibrium are fulfilled in a galvanic or electrolytic cell, the electromotive force is equal to the difference in the values of the [chemical] potential of any ion or apparent ion at the surface of the electrodes multiplied by the electrochemical equivalent of that ion, the greater [chemical] potential of an anion being at the same electrode as the greater electrical potential, and the reverse being true of a cation."

The general results of this paper are as follows:

1. The chemical potential of the zinc in the Daniell cell is greater than the chemical potential of the copper, but the electrical potential is less.

2. With electrodes which form cations the electromotive force is a measure of the difference of the chemical potentials, but has

[15] Scientific Papers, 1, 333 (1906).

the opposite sign; with electrodes which form anions it has the same sign.

3. Since the electrical potential of the copper in the Daniell cell is higher than that of the zinc, and since the zinc electrode is the place of lowest electrical potential, though highest chemical potential, we ought to use the minus sign when speaking of the electrical potential difference Zn | $ZnSO_4$.

4. Calling the zinc potential minus is in line with the practice of all physicists, of the Bunsen Society, and of the Faraday Society.

5. The distinction between chemical potential and electrical potential was stated concisely by Gibbs.

Cornell University,
Ithaca, N. Y.

DISCUSSION.

C. G. FINK[1]: At the Detroit meeting, last autumn, we had rather an animated discussion on the use of the proper signs in reference to electrodes and electrolytic solutions, we could not agree as to whether a certain electrode was plus to its solution or whether the solution was plus to the electrode, and after long debating we did not seem to be getting anywhere, so we appointed a committee of five to look into the question. One of the members of the committee became very enthusiastic on the subject, and wrote this paper. Unfortunately Dr. Bancroft is not here, but Dr. Hering, who is one of the members of the committee, will tell you in brief what the findings of the committee were.

DR. CARL HERING then read the following reports:

Majority Report of Committee on Algebraic Signs of Potentials.

1. The committee recommends that a distinction be made between the chemical potential and the electrical potential. Zinc has a higher chemical potential than copper because it will pre-

[1] Head of Laboratories, Chile Exploration Co., New York City.

cipitate copper from a copper sulphate solution. In the Daniell cell, the copper has a higher electrical potential than zinc because the current flows from copper to zinc outside the cell.

2. Since a piece of zinc in a solution of zinc sulphate is admittedly charged negatively, the committee recommends that a negative sign be placed before the numerical value which may be adopted for the single potential difference from zinc to zinc sulphate solution.

3. In accordance with the preceding recommendation, the committee recommends that the sign of the difference of electrical potential from metal to solution be made negative when the metal becomes charged negatively to the solution and positive when the metal becomes charged positively to the solution. This recommendation is in line with the practice of physicists and engineers everywhere and is in line with the practice of the electrochemists of most countries. It is sound theoretically and is the only one that can be adopted universally.

4. The committee recommends that a final decision on these points be postponed until some subsequent meeting of the Society.

(Signed) Wilder D. Bancroft,
Francis C. Frary,
M. De Kay Thompson,
Carl Hering, *Chairman.*

Minority Report.

Believing that the report of the Committee on Sign of Potentials, as presented, does not tend toward that simplicity of nomenclature and uniformity of usage which will most effectively promote the widest understanding and most extended use of data on potentials, the undersigned would amend that report to read as follows:

1. Zinc has a higher potential than copper because it will precipitate copper from a copper sulphate solution. In the Daniell cell, the zinc has a higher potential than copper because the current flows from zinc to copper i n s i d e the cell. Inasmuch as potential is conceived of as arising at the contact of electrodes and electrolyte and is measured in the electrolyte, and not outside of the cell in the air or elsewhere, it is recommended that

the positive sign for potential be made to correspond to the direction of flow of current within the cell, instead of its flow in the wires outside of the cell as in the majority report.

2. Since a table of potentials of the metals is but a means of designating by numerical values the distances between adjacent members of the "electrochemical series," and as no proposal has been made by the committee or any member of it to change the order or signs in this series, it is considered that less confusion will result, and tables of potential will be more useful, if the sign of potential of a metal is in agreement with usage in the electrochemical series and with the universal custom of calling sodium, zinc, iron, etc., positive, and platinum, copper, etc., negative, rather than to reverse the signs for the potentials of these metals as proposed in the majority report. The futility of attempting to represent completely the electrical conditions in the voltaic cell by attaching a single sign to either electrode was recognized by the early electrochemists when they spoke of the zinc as "the positive plate (we should now say electrode), but the negative pole of the cell." There is yet to be found a simpler way of designating the relation of the zinc electrode to the whole electrical circuit; for current will flow from the zinc into the electrolyte provided that it be permitted to return to the zinc again from that portion of the circuit which lies outside of the cell; yet the driving force resides within the cell.

3. The committee accordingly recommends that this society go on record as favoring the continuation of the long-established custom of designating sodium, zinc, etc., as positive, and copper, platinum, etc., as negative in tables of potentials, believing that this practice will best promote progress in electrochemistry.

(Signed) Oliver P. Watts.

Carl Hering[2]: I might say, in my own behalf, from the electrical standpoint, that we now know that those who established what we now call the direction of the current, unfortunately guessed wrong. They guessed that it flowed in a certain direction and they therefore called a certain pole positive and the other negative. We know now that the current really flows in the opposite direction to what our forefathers guessed; there-

[2] Consulting Electrical Engineer, Philadelphia, Pa.

fore that which accumulates is negative electricity and therefore it ought to be designated with a positive sign because it represents an excess or accumulation, as distinguished from a deficit. Things that are positively charged we know today are those from which the negative has been taken; therefore electrically, the signs ought to be reversed, but that will probably never be done. Physically, therefore, a high chemical potential does agree with a high electrical potential. If we consider that it is an accumulation of a negative charge, not of the positive, that determines the electrical potential, we are as a matter of fact in agreement.

J. W. Richards[3]: My sympathies and conclusions are more with Dr. Watts than with the majority of the committee. We measure potential as higher and lower. I object strongly to having it said that the electrical potential of zinc is less than that of copper, unless it is stated that it is algebraically less but numerically greater. It is in reality numerically greater, but (as the majority report would express it) in the algebraic sense it is less, because it is minus a greater quantity. I think the majority conclusion would cause great confusion, just because it makes no distinction between the algebraic and the numerical values. Reasoning from another standpoint, we are so certain that the chemical and the electrical potentials of the elements are very nearly if not absolutely in accord numerically, that to adopt a statement which appears to make them practically the opposite of each other, would be most unfortunate.

Dr. Carl Hering: One reason why we did not present a final report is because we wanted to hear what the members had to say at this meeting; so if anybody who is interested in this subject will kindly send to the Secretary or to me anything they choose to say about it, we will be glad to take it under consideration and then present our final report.

[3] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

AN EXPERIMENTAL CARBON CELL.

By S. Albert Reed, Ph.D.*

Abstract.

A primary battery is described in which the electrolyte is fused borax containing manganese dioxide, the negative pole is broken carbon in contact with a graphite grid and floating on the melt, while the positive poles are strips of gold foil. The carbon is kept inside a cylindrical shell of siliceous material (a sawed-off crucible), while the melt is contained in a shallow clay roasting dish, in which the cylinder stands. The air oxidizes the electrolyte in contact with the outer gold strips, while the carbon reduces the electrolyte inside. Mixtures of CO_2 and CO are produced at the anode. The voltage averages 0.8. Temperature 935° to 990° C.

Although the problem of the direct production of electricity from fuel was at one time the subject of numerous patents and also of papers read before this and other scientific societies, the prospect of a commercial solution is not encouraging. The apparatus herein described has no pretensions in a practical direction, but is a laboratory device easily made and with which any student having a muffle furnace at his disposal can determine quantitatively the conditions attending the direct production of electricity from carbon with a fused electrolyte. The form the apparatus now has is the final result of numerous trials having in view to test the suggestions of patentees and others, but the main purpose is the development of a carbon-consuming battery of constant character which can be operated without interruption for indefinite periods, as is the case with other constant cells such as the

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LeClanché or the Bunsen. With such an apparatus it is possible to determine, and have for permanent scientific record, the constants of the cell, its voltage, internal resistance and polarization, as is the case with the other cells named. Having such an instrument to work with, it has been also in view to take up later the interesting and important question of efficiency, and to ascertain quantitatively the percentage of fuel energy convertible into electric energy and the relation of such efficiency to the stage of oxidation of carbon reached, whether to CO or to CO_2 or to both, and the relation of these conditions to the temperature at which the cell is operated.

Some of the requirements which I found necessary to make a cell which could be operated continuously without replenishment of anything except fuel are those which will probably apply equally to a commercial apparatus if such is ever worked out, and are as follows:

1. The electrolyte must not be consumed in the operation of the cell.

This precludes any fused salt which forms carbonates, and points to the use of an acid glass. Such would be an acid silicate or borate, and the latter is preferable on account of its lower temperature of fusion.

2. The electrodes must not be consumed in the normal operation of the cell. At the oxygen-absorbing end (cathode) a cell with an acid electrolyte has a disadvantage as compared with a cell having a basic electrolyte, since if a fused borate or silicate is used every metal except gold or platinum is promptly oxidized and dissolved. At the oxygen-utilization end (anode) this condition also precludes the use common to most proposed carbon cells, of the fuel in a formed or moulded shape, the purpose of which is to maintain immersion and to permit the mechanical attachment of a terminal conductor. The objection to such an arrangement is that there is the necessity of interruption for replacement and no continuous operation is possible.

3. No air blowing or other mechanical attachments can be allowed.

4. The gaseous product of the cell must have free escape.

The cell I have found to meet these requirements is shown in cross section in Fig. 1. It uses as electrolyte fused borax having in solution as an oxygen conveyor oxides of manganese. A convenient proportion used by me is 80 percent powdered fused borax and 20 percent powdered "heavy" manganese dioxide. The unattacked electrode at the oxygen-absorbing end (cathode) is gold or platinum, and I have preferred to use dentist's gold foil cut into ribbons and connected with a gold terminal wire. This foil floats smoothly on the fused borax and thus is not only

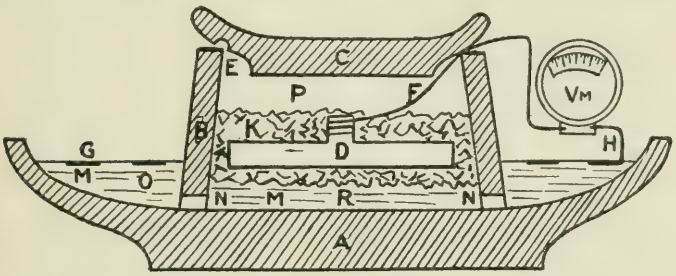


FIG. 1.

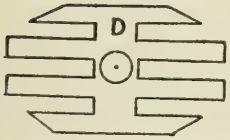
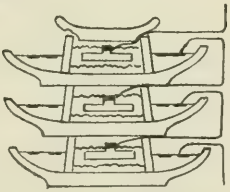


FIG. 2.

FIG. 3.



A—Six-inch Battersea Roasting Dish. B—Section of Three-inch (7.5 cm.) Battersea Crucible. C—Cover. D—Graphite Electrode. E—Aperture for Escape of Products of Combustion. F—Wire Conductor to Voltmeter. G—Gold Foil Electrode. H—Wire Conductor to Voltmeter. K—Broken Coal. M—Fused Borax with Oxides of Manganese in Solution. N—Communication Passages. O—Oxidizing Region. P—Waste Gas Chamber. R—Reduction Region.

self-adjusting as to position and immersion but is in a favorable place for co-operating with the oxidation by air at the surface of the electrolyte.

The electrode at the fuel end of the cell (anode) is graphite cut into a grating form as shown in Fig. 2, and kept buried in the fuel which, in the case illustrated, is broken anthracite coal in pieces not over ⅛ inch (3 mm.) diameter. The fact that coal and other forms of carbon float in fused borax with a considerable proportion unimmersed makes it possible to maintain a layer of fuel thick enough to keep the buried graphite electrode free

from contact with the electrolyte below or the gases above the fuel, and, while maintaining good conductive contact with the latter, will yet permit the free escape of gaseous products of combustion. The grating form of the electrode also is designed to permit this free passage of gas and also the free descent of the fuel to contact with the electrolyte. The flotation of the fuel also lends itself to the arrangement I have worked out, whereby the use of a porous diaphragm is avoided and the separation of the cell into an oxidizing and a reducing region is effected by a hydraulic seal consisting of a curtain of refractory material dipping into the fused electrolyte. The layer of fuel is maintained at a thickness which will keep the immersed portion at a level safely above the lip of the hydraulic seal, thus preventing the passage of fragments of fuel into the oxidizing region where they would float to the surface, and would tend to neutralize the oxidizing conditions there to be maintained.

The combustion or reduction region is closed at the top by a movable cover, for replenishment of fuel, and has a small aperture for the escape of gaseous products of combustion and for the passage of the terminal conductor attached to the graphite electrode. This cover excludes air, so that the upper surface of the fuel is exposed only to CO and CO_2 and oxidation can occur only at the lower and immersed surface and at the expense of the oxygen of the higher manganese oxide dissolved in the electrolyte.

Re-oxidation of this manganese oxide can occur only at the surface of the liquid outside the reduction chamber, where it is exposed to a regulated circulation of fresh air admitted into the furnace and thereby heated. The general form of the cell, it should be noted, tends both at the oxidizing and reduction ends towards extended and shallow surfaces, and the dish or pan form of the container lends itself conveniently to combination with other elements to form a battery of cells as indicated in Fig. 3.

There is a presumption that MnO will be formed at the carbon end and MnO_2 at the oxygen end, and the white patches found near the coal when cooled and broken indicate that such is the case. But the reactions may not be so simple, and Mn_2O_3 may enter into the sequence of reactions.

As in all other primary cells there will be a gradual contamination of the battery liquid by accumulation of impurities derived from the fuel, but the replacement necessary is probably no more considerable than in the case of other chemical batteries in practical use. The borax is assumed to take no part in the chemical reactions, and the reduced manganese oxide is constantly re-oxidized; therefore there is theoretically no consumption of the battery fluid.

To anyone proposing to repeat my experiments, I advise fusing the borax and manganese oxide together in a separate vessel until in smooth fusion, then pouring, cooling and crushing to granular form. The cell may then be built up cold with each part in exactly its proper place. It is then placed in the muffle and heated gradually to fusion, when current will immediately flow.

The following record of some of my experiments indicates the general character of the constants determined:

Average of Six Tests of Single Cell Using Anthracite Coal.

Coal surface ..... 8 sq. inches (50 sq. cm.)
Oxidizing surface .....14 sq. inches (87 sq. cm.)

	Average of Six Tests Single Cell	Av. of Six Tests 2 in Parallel	Av. of Six Tests 2 in Series
Open circuit voltage after five minutes open circuit	0.9 volt	0.857 volt	1.7 volt
Open circuit voltage after one hour—closed circuit on 4⅓ ohms resistance	0.82 volt	0.837 volt	1.5 volt
Drop in voltage	9 percent	2.3 percent	12 percent
Amperes on closing circuit.....	0.185 amp.	0.184 amp.	
Amperes after one hour through 4⅓ ohms	0.157 amp.	0.172 amp.	
Ampere drop	14 percent	6½ percent	

Polarization, inferred from drop in voltage and amperage, is seen to be low. Internal resistance from above averaged 5 ohms per square inch (0.8 ohm per sq. cm.) of carbon contact with the electrolyte.

This latter figure corresponds closely to the internal resistance of a Bunsen cell. The voltage after experiencing the above noted nine percent drop on closing the circuit remained constant indefinitely. The temperature of the furnace should be sufficient to

give good, smooth liquid fusion, and any higher temperature does not appear to materially affect the output of current. About 1,700° to 1,800° F. (935-990° C.) is a convenient temperature. Ordinary fire-clay dishes are attacked by the fused borax glass, and this would be expected from their basic character. They are apt to be slowly eaten through and in five or six hours leaks are likely to develop through which the entire contents soon flow.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918, President Fink in the Chair.

THE CALCULATION OF STORAGE BATTERY CAPACITIES.[1]

By C. W. Hazelett.[2]

Abstract.

The use of three million storage batteries for automobile starting purposes imposes new conditions of service which former methods of determining capacities do not cover satisfactorily. It is important that final voltages be standardized as a continuous function of the time rate of discharge, in order that the condition of the cells at end of discharge at any time rate shall be approximately the same, and that all capacity data may be correlative. An equation for this final voltage is suggested.

The work of Messrs. Spencer and Naiden is reviewed. They demonstrated that the capacity of the starting battery was a single, definite function of the time. The development of an alignment chart and circular slide rule for calculating storage battery capacities is shown. The proper methods of selecting charging and finishing rates are suggested.

The use of the storage battery for starting, lighting and ignition on the modern automobile requires it to work under very different conditions than those to which it was subject when Lyndon, Dolezalek, Morse, and others wrote their excellent treatises on the accumulator. These new conditions require the revision of certain formulæ to cover the increased ranges of operation, and the fact that there are three million batteries in use for starting and lighting purposes emphasizes the practical importance of selecting the proper foundation for calculating the characteristics of these batteries and for future research work.

[1] Manuscript received March 8, 1918.

[2] Storage Battery Engineer, National Carbon Company.

Since the voltage of an accumulator cell decreases continuously throughout the discharge, and the current is generally held approximately constant, it is customary to rate the capacity of a battery in ampere hours, the end of discharge being determined by a definite limiting voltage of the cell. Before storage batteries were used on automobiles, the determination of the characteristics between the one hour and the twelve hour discharge rates covered the range of practical application. However, it has become necessary to measure and predetermine their capacities and voltage characteristics from as low as the 3-minute rate of discharge to as high as the 160-hour rate, the former applying to starter operations and the latter to ignition work.

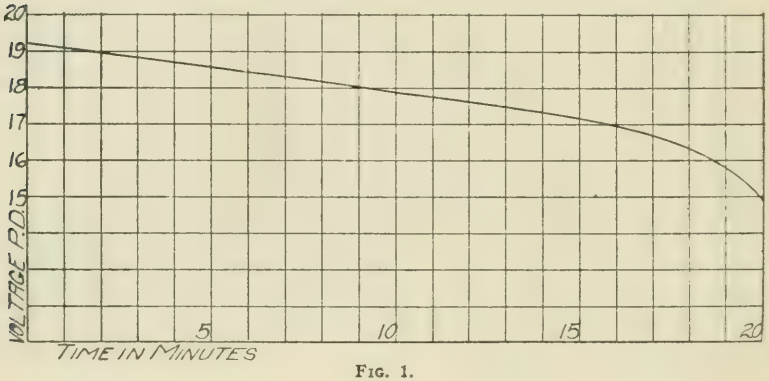


FIG. 1.

It is well known that the product of the current and time of discharge, or the capacity, decreases with increasing current values. This is due to the fact that at high rates lead sulphate is formed principally on the surface of the plate, because the electrolyte does not have time to diffuse to any large extent into the interior pores of the plates. This sulphated material, having a higher volume than the charged active material, decreases the size of the pores, further preventing the diffusion of electrolyte into the plate. These effects, combined with the increase of internal resistance due to the formation of lead sulphate, causes the E. M. F. to drop much more rapidly than it would at small current rates.

Since the capacity is determined by a limiting voltage of the cell, it is very important that this be properly selected and stand-

ardized in order to make research and technical data correlative. Fig. 1 shows that if 1.8 volts was used for the limiting voltage, the duration of the discharge would be about 9 minutes, while if 1.7 was used it would be almost 16 minutes.

Lyndon gives the following equation for final voltages:

$$E = 1.66 + 0.0175\ T$$

With this equation, at a practical time rate of discharge, for example, 40 hours, it makes the final voltage equal to the initial voltage, and at higher discharge rates results in an absurdity, the final voltage being higher than the initial voltage. At extremely low rates, the final voltage approaches 1.66 as a limit, while 1.2 is a practical final voltage at the 5-minute rate. Theoretically, the final voltage should approach zero at zero time.

Dolezalek goes to some length to prove several empirical equations governing capacities by theoretical methods, and practically ignores the effect of limiting voltage. The importance of this omission is shown by the fact that the capacity of a cell at any rate would be a constant provided the final voltage was defined accordingly. The actual limiting factors are the practical ones, and the following values for the final voltages, determined from experience, are almost universal standards:

Time Rate	Final Cell Voltage	
5 minutes	1.2	(Government specifications)
20 minutes	1.5	(Standard for all starting battery manufacturers)
	1.7	(Standard for starting battery manufacturers at the 5-ampere rate of discharge)

(The 5 ampere rate of discharge is the 20-hour rate on the average and most popular type of starting battery.)

Theoretically, it is desirable to set the final voltage so that the more or less critical point of sulphation is not exceeded, and that the drop of voltage in the cell due to sulphation shall be the same at the end of discharge regardless of the rate, or, in other words, it would be desirable to subtract from the practical final voltage used at the lowest current rates, the drop in voltage due to a given time rate of discharge which cannot be attributed to sulphation. Good practice of many years shows that 1.85 final volts per cell is entirely satisfactory at the lowest current rates.

If we subtract from this value the drop of voltage which is due to concentration effects and internal resistance (not caused by sulphation or the discharged conditions of the plates) found at various time rates of discharge, we should get values which, plotted with the time rate, would give the correct final voltages for various time rates. Our equation would then read $E = 1.85 - f(T)$.

To determine this drop of voltage, fully charged starting-battery type cells were discharged at various known time rates of discharge (the final voltage being considered a constant) and the drop in voltage read after two minutes, this time being required for the voltage to reach a fairly steady value; that is, for the

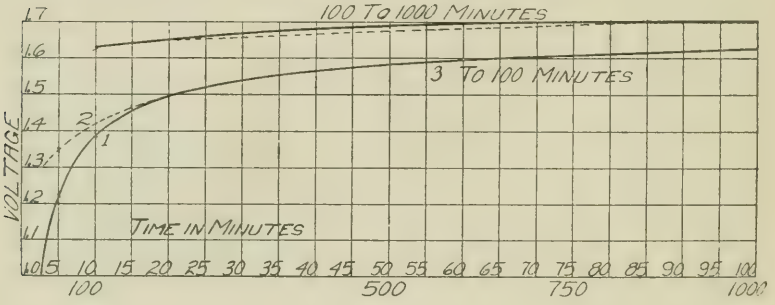


FIG. 2.

rate of diffusion of electrolyte to balance its consumption in the plate.

Curve No. 2, Fig. 2, was found by subtracting from 1.85 the drop in voltage found due to the different time rates of discharge. This drop was of course the difference between the open circuit voltage of the cell and that measured when the current was flowing. This curve evidently approximates the equation

$$E = 1.85 - \frac{K}{\text{Log } T}$$

Taking the values of E as 1.5 at the 20-minute rate and 1.2 at the 5-minute rate, and substituting in this equation, we find the value of K to be 0.448. This equation is plotted in Fig. 2, Curve No. 1. The agreement is really good when it is remembered that at very low time rates the experimental error is likely to be very large. Fortunately, this curve is almost exactly 1.7 volts at the

5-ampere rate on the average size starting battery. The curve approaches zero at one-minute time, and thus conforms quite satisfactorily with both theory and practice.

The policy used by some concerns of making the final voltage dependent on the current rate of discharge is very unfortunate. When a cell having a small number of plates is discharged, say at five amperes, to 1.7 and a cell having a larger number of the same type plates is discharged at the same rate to the same voltage, the former will have become more seriously sulphated on the surface of the plate than the latter, on account of the higher current density and increased surface sulphation mentioned above.

Peukert originated a most useful equation for calculating storage battery capacities, which is practical within certain limits, where a slight difference in the final voltage is of little importance. It is $I^N.T = K$, where I is the current, T the time and K the constant for a given cell. If we take the logarithm of this equation, we have $N.\text{Log } I + \text{Log } T = K'$. We are indebted to Mr. Thos. Spencer for having shown that the capacity of modern starting and lighting batteries is a single definite function of the time rate of discharge, that is to say, he plotted a curve showing accurate relation between the current and the time of discharge of one type battery and found that the same curve could be used for any other battery of this type providing the current was divided or multiplied by the proper constant. Plates used in these batteries vary 35 percent over the minimum thickness and 57 percent over the minimum area, and there are some slight differences in construction in the various types. He plotted his curve on logarithmic section paper, which has the important advantage of giving accuracy at low values. His results are confirmed by the very extensive and accurate investigations of Mr. J. H. Naiden, who also found that it was necessary to make the final voltage a continuous function of the time.

The heavy lines in Fig. 3 are the capacity curves of two widely different type batteries, plotted on logarithmic section paper. Between the limits shown, it is evident that the curves approximate straight lines very closely, that is, N or the tangent the line makes with the current axis is very nearly constant. However, as we increase the range to higher current rates, we find that N varies in the practical limits 200 percent, and that it is a function of

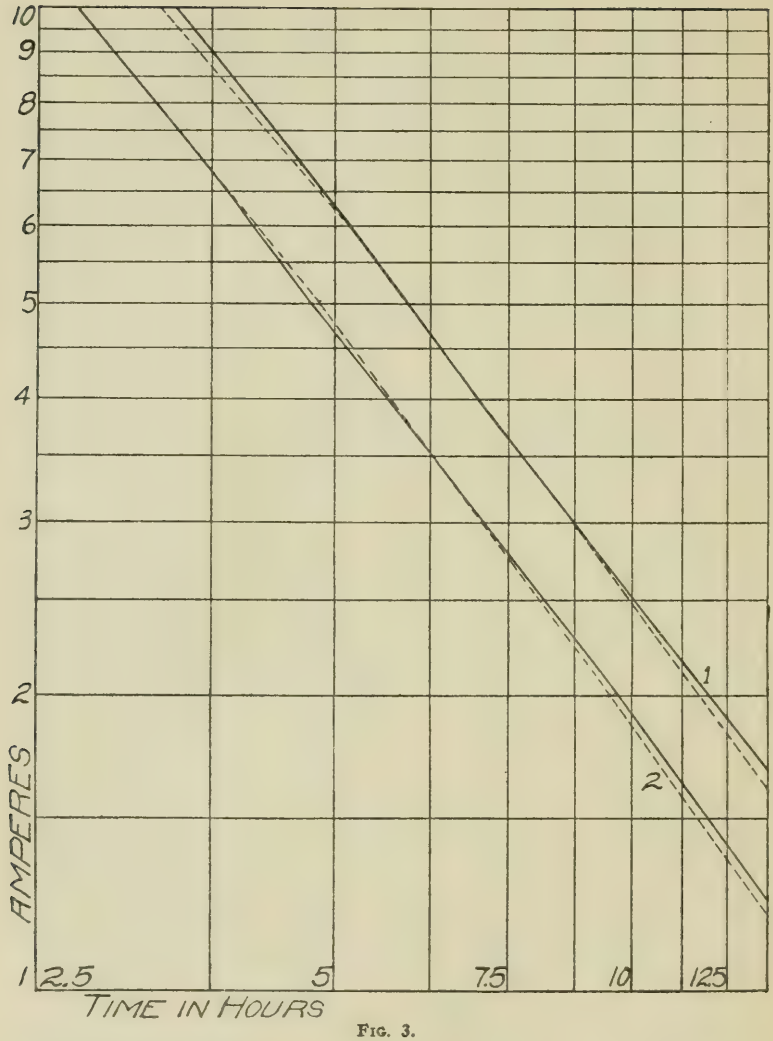


FIG. 3.

the time. Peukert's equation is then not satisfactory for modern conditions. Dividing his equation by N, we have

$$\text{Log } I + M \text{ Log } T = K''$$

where M equals the reciprocal of N. It is my purpose to show that M is a definite function of time when this equation is applied

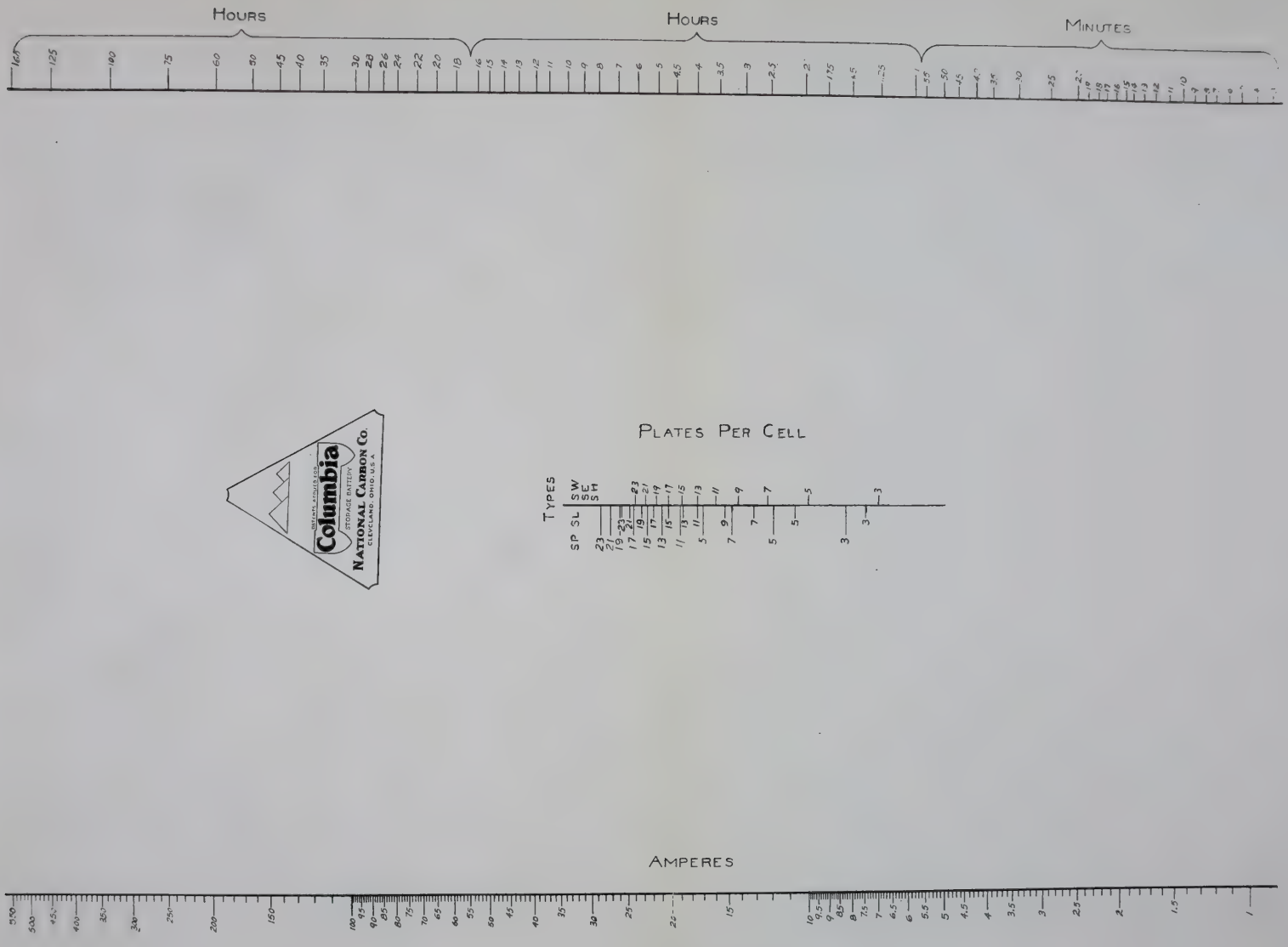
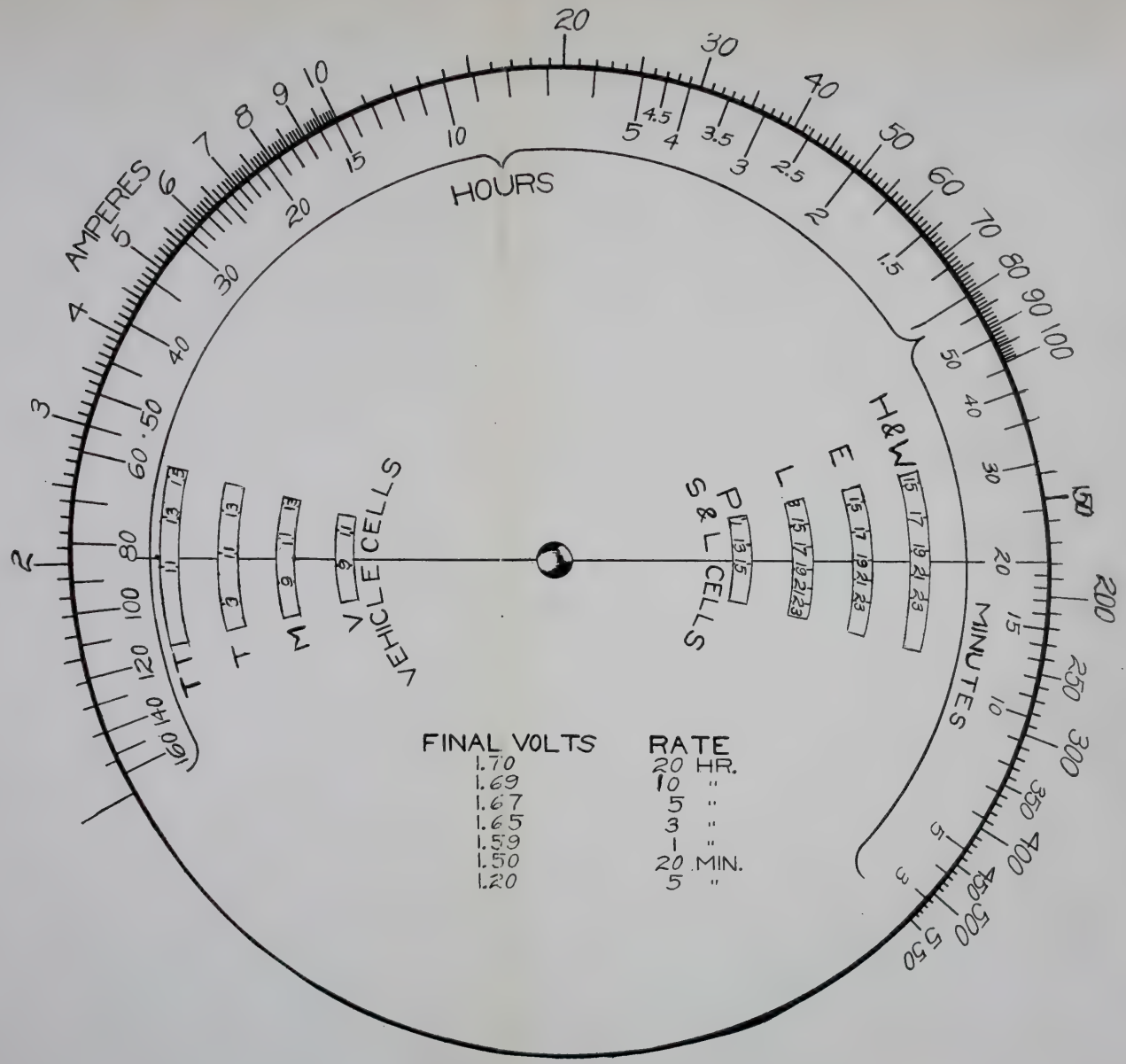

HOURS
HOURS
MINUTES
Columbia
STORAGE BATTERY
NATIONAL CARBON CO.
CLEVELAND, OHIO, U.S.A.
PLATES PER CELL
TYPES
SP SL
SW
SE
SH
AMPERES

FIG. 4.


AMPERES
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FINAL VOLTS
1.70
1.69
1.67
1.65
1.59
1.50
1.20
RATE
20 HR.
10
5
3
1
20 MIN.
5

FIG. 5.

to starting, lighting and vehicle batteries of the pasted type, and possibly for all types over the ranges required in modern practice.

It will be asked, does not the relation between a battery's capacity at high and low rates depend upon the thickness of the plates. As a matter of fact it does, but the variation if this relation between the limits required in modern commercial practice is not over 5 percent from a mean, and since this is considerably less than the average experimental error and very much less than the variation found in any operating conditions, it may be neglected. We first attempted to devise a means of calculating capacities at any rate, the capacities at given rates being known on a particular size cell of a given construction. A large number of tests were taken and were plotted on an alignment chart shown in Fig. 4.

The left-hand vertical line, or current axis, is plotted logarithmically. An arbitrary point on the center line indicating a certain cell was then chosen. The proper value of the time was then plotted on the right-hand line so as to be on a straight line connecting the arbitrary point on the center line and the corresponding current at the left. The right-hand scale is MT Log T or (f) T Log T or simply $(f')T$. Other points were determined on the center line corresponding to different sizes or type of cells. This chart worked very satisfactorily as far as we developed it; however, it had the disadvantage of requiring the use of a separate straight edge which covered up the figures and types and the number of points which could be shown on the center line was limited. The accuracy of this device for a convenient size was not very great.

A circular slide rule was then constructed (Fig. 5). This has a stationary scale plotted as the logarithm of the current, and a rotating dial with (f) T Log T plotted thereon from fact. The constant of the equation, which in this case is the corresponding cell instead of a numeral, is indicated by the radial line. If we set this radial line on the mark indicating a given cell, or set any known time of discharge opposite the corresponding current, the time of discharge for that cell at any other rate will be found opposite that rate, and *vice versa,* if M or (f) T in our equation is a single and definite function of the time. If the calculator is calibrated in the type cells as this one is, when the required

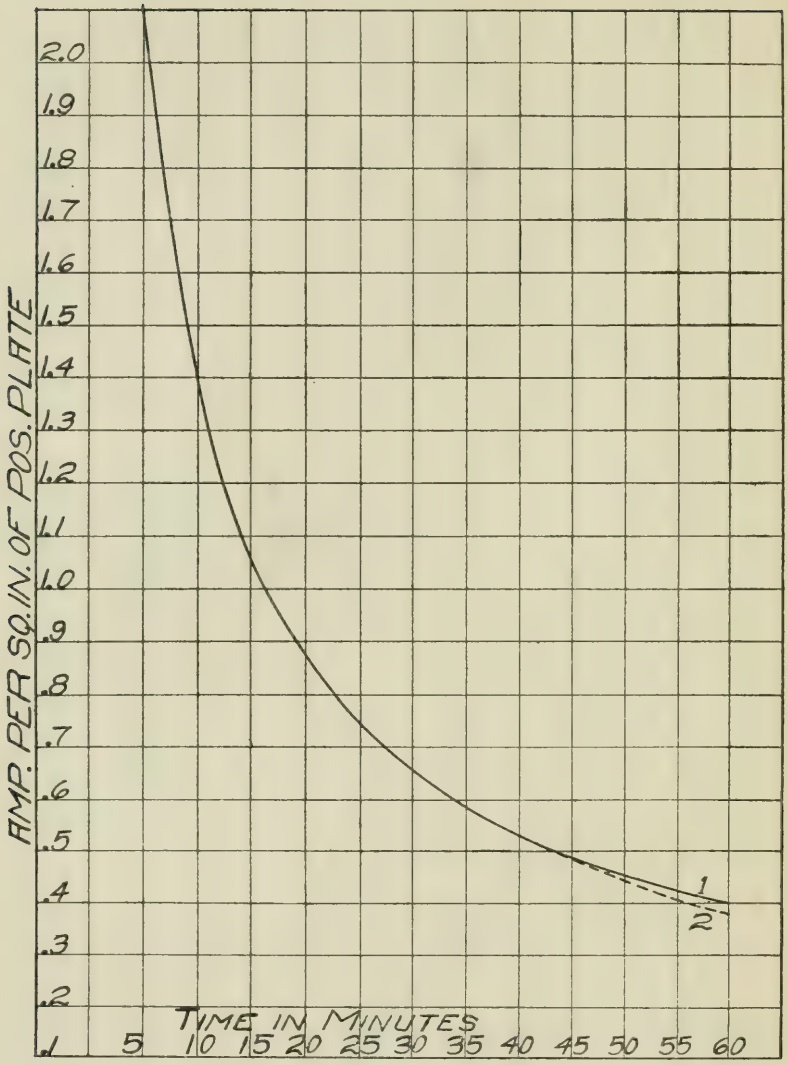
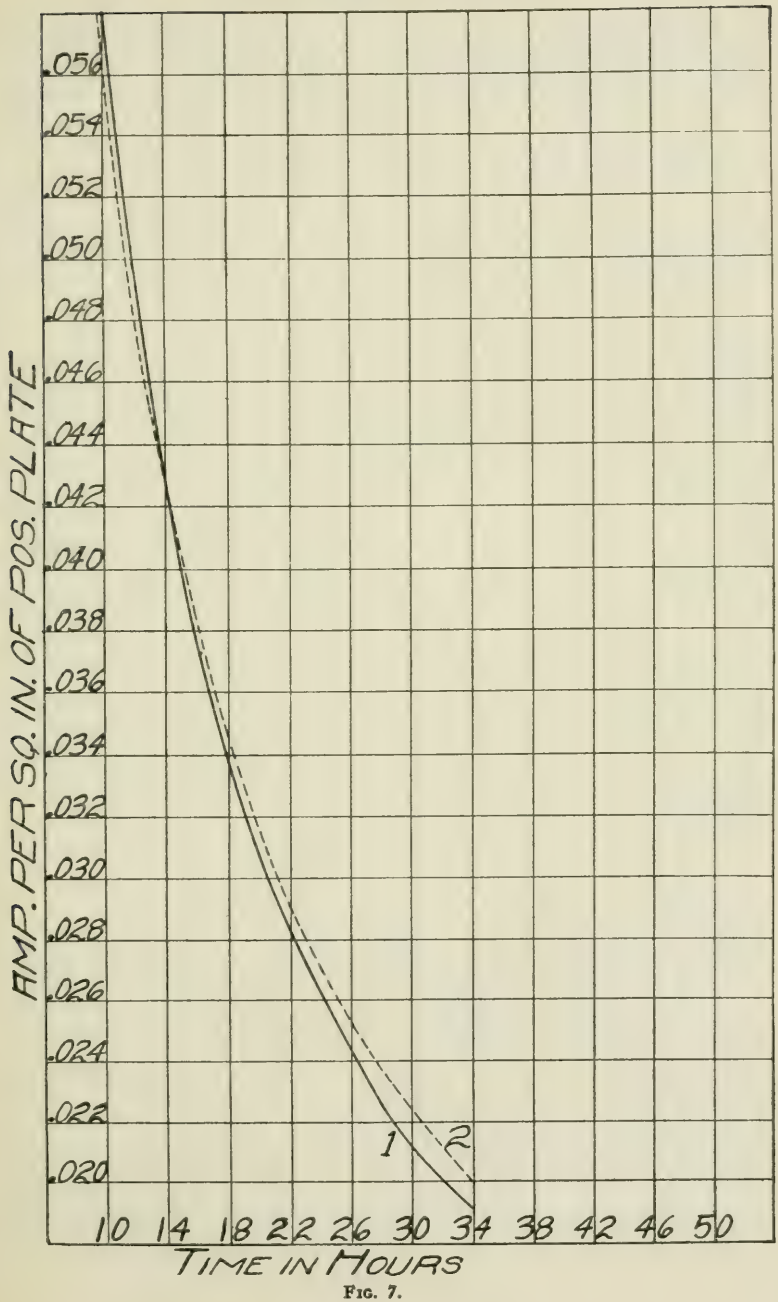


FIG. 6.

current and the desired time of discharge are placed opposite one another, the proper type cell is indicated by the radial line.

To check the accuracy of this device, its indications were compared with the published curves of several leading manufacturers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.028
.026
.024
.022
.020
AMP. PER SQ. IN. OF POS. PLATE
1
2
10 14 18 22 26 30 34 38 42 46 50
TIME IN HOURS

FIG. 7.

covering a wide range of construction. Comparing its readings with the data published by a very large manufacturer of starting batteries whom we have reason to believe has done the most

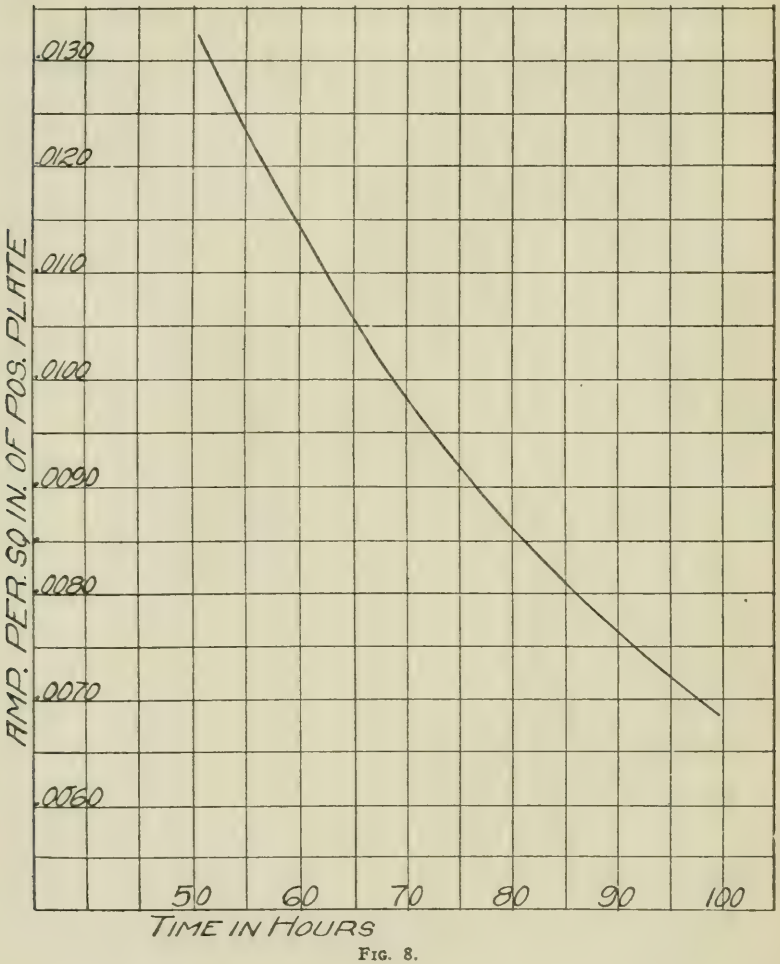

FIG. 8.

painstaking research along this line, they were found to be identical from the 5-minute to the 60-hour rate, that is, in the limits published. Some curves which were the work of Mr. Naiden were checked and the results are shown in Figs. 6, 7 and 8. The dotted line (where visible) indicates the calculated value, and the

full line the observed value. The foregoing applies only to Faure or pasted type starting and lighting batteries. Reference to Fig. 3 shows the calculated and very accurately recorded data on two representative type vehicle cells, plotted on logarithmic paper.

No. 1 is a pasted plate 75 percent thicker than the plates on which the calculator is based. No. 2 is the "Iron Clad" Exide type.

The agreement is seen to be excellent over the range shown, which is all that is required in practice. Having shown that the

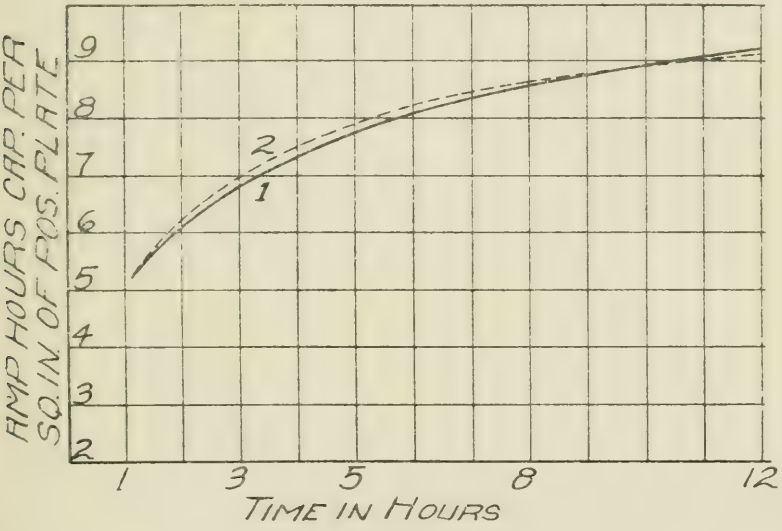

FIG. 9.

capacity is the same function of the time for these widely varying constructions in the time limits given, the writer checked $f(T)$ for submarine cells. The results are shown in Fig. 9.

The cells were of the Planté positive, pasted-negative type. The agreement is remarkably accurate, but I would not wish to state that the capacity is the same function of the time for Planté plates as it is for the pasted type, as I have not done sufficient work along this line. The fact, however, that the calculator gives such accurate results when compared with the most carefully acquired data on the smallest, thinnest starting battery plates, the thickest, pasted vehicle plates, the "Ironclad" Exide, and the enor-

mous submarine types, leads us to conclude that the capacity of a storage battery is a definite function of the time rate of discharge, and practically independent of the form of construction.

The ability of a battery to furnish current is in direct proportion to its ability to absorb it properly on charge, since they are both equally dependent upon plate area, thickness, porosity, internal resistance of the cell, etc. In other words, the charging current should be the same as some definite time rate of discharge. The average of the charging rates recommended by manufacturers is approximately the 7-hour discharge rate, while the finishing rates or charging currents used to give a cell the proper overcharging without causing excessive gassing average near the 18-hour discharge rate; therefore, when the radial line of the calculator points to a given cell, or any current is placed opposite the corresponding time rate of discharge for a given cell, the proper charging rate will be found opposite 7 hours and the finishing rate opposite 18 hours. I might add, however, that the practical method of charging, where constant attendance is possible, is to use the highest rate possible without raising the temperature of the cell above 110° F. (43° C.), or causing excessive gassing.

It must be remembered when using this calculator to check tests on storage batteries, that the experimental error under ordinary conditions may be very great. If a cell is not fully developed, an error of 25 percent may obtain between two successive discharges, a decrease in temperature of 20° F. (11° C.) may decrease the capacity 20 percent at some rates. 80° F. (26° C.) is the Society of Automotive Engineers' standard temperature of the electrolyte for automobile starting batteries at the beginning of discharge. 70° F. (21° C.) is standard for most other types. The initial density of the electrolyte must be uniform throughout the cell, while a slight difference in the electrolyte density or in the reading of the density may cause an important error.

CONCLUSIONS.

1. The systematization of storage battery testing demands that all data shall be based on time rates if they are in any way to be universal.

2. The capacity of any Faure or pasted-type starting battery

cell between the time limits of 5 minutes and the 100-hour rates of discharge, and of all commercial-type vehicle plates between the 30-minute and 12-hour rates, is a definite single function of the time; *i. e.*, Log $I\ f(T)$ (Log T) $= K$, where I is the current, T the time, K the capacity in ampere hours times some constant, and $(f)(T)$ a definite function of the time.

3. It is essential to have a universal final voltage equation which is scientific and a definite function of the time. The formula

$$E = 1.85 - \frac{0.448}{\text{Log } T} \quad (T \text{ given minutes})$$

is offered as a scientific and practical equation.

4. The charging and finish-charging rates of any cell should be a definite time rate of discharge. The 7- and 18-hour rates are respectively recommended.

5. A device for calculating the capacity of storage batteries at various time rates of discharge is shown.

DISCUSSION.

P. G. Salom[1]: This paper is really a very valuable contribution to the storage battery question, which is becoming more and more important in view of the enormous number of storage batteries used for motor-starting and lighting purposes.

Standard discharge rates should undoubtedly be established, but it is questionable if such rates should be based entirely on ampere-hour capacity. For example, in starting batteries where a high rate of discharge is required for a comparatively short time, and where the battery can be re-charged continuously if desirable or necessary, it is evident that ampere-hour capacity is secondary, provided there is sufficient surface area to maintain high rates without serious drop in voltage. Therefore it would seem that the type of battery best adapted for this purpose would consist of thin plates of a maximum surface area which would admit of high rates of discharge for short periods.

[1] Electrochemical Engineer, Philadelphia, Pa.

CARL HERING[2]: If a storage battery is discharged at constant wattage instead of constant current, the question of the voltage determining the service falls out entirely; no question then arises as to the voltage at which one must stop the discharge; it settles itself and is equally fair to all types of cells.

C. G. FINK[3]: We have had quite a number of papers on the standardization of the dry cell, and it is interesting to see that the wet cell or storage battery requires a little standardization too.

[2] Consulting Electrical Engineer, Philadelphia, Pa.
[3] Head of Laboratories, Chile Exploration Co., New York City.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

THE ELECTROLYTIC BEHAVIOR OF MANGANESE IN SULPHATE SOLUTIONS.[1]

By G. D. van Arsdale[2] and C. G. Maier.[3]

Abstract.

The object of this investigation was to study the current efficiencies, voltages, and conditions affecting the nature of deposits formed by electrolyzing manganese sulphate solutions. The factors affecting the deposition of elementary manganese at the cathode are discussed. The efficient plating out of manganese dioxide at the anode is shown to be possible under certain circumstances, and the chemical conditions influencing the possible utilization of this reaction are pointed out.

Introductory.

In pre-war times the manganese ore needed for the steel and other large-scale industries of this country was supplied by importation largely from Russia. Since the outbreak of the war importation from this source has stopped.

There are large deposits of metallurgical manganese ore in Brazil, and fairly extensive, although largely undeveloped, deposits in this country. The two alternative solutions of the problem, therefore, have been either the diversion of sufficient shipping for importing manganese ore from Brazil, or the development and utilization of our domestic deposits. Since shipping has been, and is, so urgently needed for other purposes, the second alternative would appear to be desirable, if possible. Moreover, since it is at least possible that the importation of high-grade ore will

[1] Manuscript received March 8, 1918.
[2] Consulting Chemist, Phelps-Dodge Corporation.
[3] Assistant Chemist, Research Department, Phelps-Dodge Corporation.

be seriously hindered for even a considerable period after the war, the use of domestic ore is not entirely one of immediate or temporary expediency.

Our own deposits of manganese oxide and carbonate ore while fairly extensive are, unfortunately, many of them, of too low grade to be of much direct use. Mechanical concentration of these ores has been unsatisfactory, particularly from the point of view of efficiency of recovery. Smelting of low-grade ores will always be attended with serious difficulties and large slag losses. It seems, consequently, that some chemical method of concentrating ores might be the best solution of the present problem, and, if well established, might even persist in post-war conditions.

This paper presents some preliminary results of work done in an attempt to solve the problem along electrochemical lines. Methods which might be developed from the results presented in this paper will probably not be adapted to the production of manganese for ferro-manganese, or other large-scale metallurgical use, but the data obtained are of interest not only theoretically but may also be of practical use for the production of manganese dioxide, particularly for dry-battery use.

It was early realized that the most practical and convenient avenue for separating manganese from its ores was solution as manganese sulphate, and such a solution is also the form most amenable to electrolytic treatment.

In the case of carbonate or oxide ores, leaching with sulphuric acid, or with peroxide ores leaching with gaseous sulphur dioxide, affords a cheap and efficient method of separation from gangue constituents. Recoveries of from 80 to 100 percent are possible on most ores by these methods.

It has, moreover, long been known that manganese may be electrolytically deposited at the anode as peroxide, from certain types of solutions, and Foerster[4] states that it is also possible to deposit some manganese at the cathode in elementary form, provided high-current densities and strong, nearly neutral, solutions are used. No data as to current efficiencies were, however, obtainable, so that it became the proximate purpose of this research to determine these quantities, as a preliminary to working out a practical process.

[4] Electrochemie wässeriger Lösungen, p. 196.

In any electrolytic method in which either metal or oxide is separated from salt solutions at the electrodes, the electrolyte must necessarily build up in acid, which may be further used for leaching or other purposes. The practicability of such processes is, of course, largely a matter of cost and the possibility of inhibiting the results of side reactions. At any rate, to figure out a "paper" process is easy, but its usefulness depends on the measurable quantities of current efficiency, voltage, and other factors which it was the purpose of this work to ascertain.

Naturally this work divides itself into two main divisions: the effects at the anode, and at the cathode. The results are treated in the sections below.

Part I.

The Electrolysis of Manganese Sulphate Solutions to Produce Mn at the Cathode.

The theoretical voltage Mn | Mn^{++}, compared to the hydrogen electrode in molal solutions, is + 1.1 volts, and since MnO_2 is usually the product at the anode, with a voltage, under similar circumstances, of — 1.35 volts, the theoretical voltage of the cell Mn | $MnSO_4$ | MnO_2 should be 2.45 volts, yielding a maximum possible deposition of manganese at the cathode of 0.943 lb. (0.433 kg.) per K.W. hour.

Fig. 1 shows the current efficiencies and voltages actually obtainable in *fresh* neutral molal solutions of manganese sulphate, at various current densities. The efficiencies are satisfactory over a wide range of amperages, with a maximum of about 90 percent at 20 amperes per sq. ft. (220 per sq. meter). It is true that the voltage is very high, but since MnO_2 is also produced at the anode, and as this should have a marketable value, the mere matter of voltage alone would not be prohibitive for practical operation. There are, however, two rather serious difficulties entering into the problem of depositing metallic manganese, as follows:

(*A*) The first of these is the fact that the deposit, under the conditions of the experiments we made, is of a dark greyish, powdery character, oxidizing in air with great ease. These characteristics are doubtless due to the fact that manganese comes so considerably above hydrogen in the electromotive series that

hydrogen is inevitably produced, even in neutral solutions, in sufficient quantity to make obtaining a coherent metallic deposit very difficult.

Attempts to improve the deposit by rotation of cathode, the use of polishing devices, changes in the surface and kind of starting cathode, and use of a few addition agents, were without marked

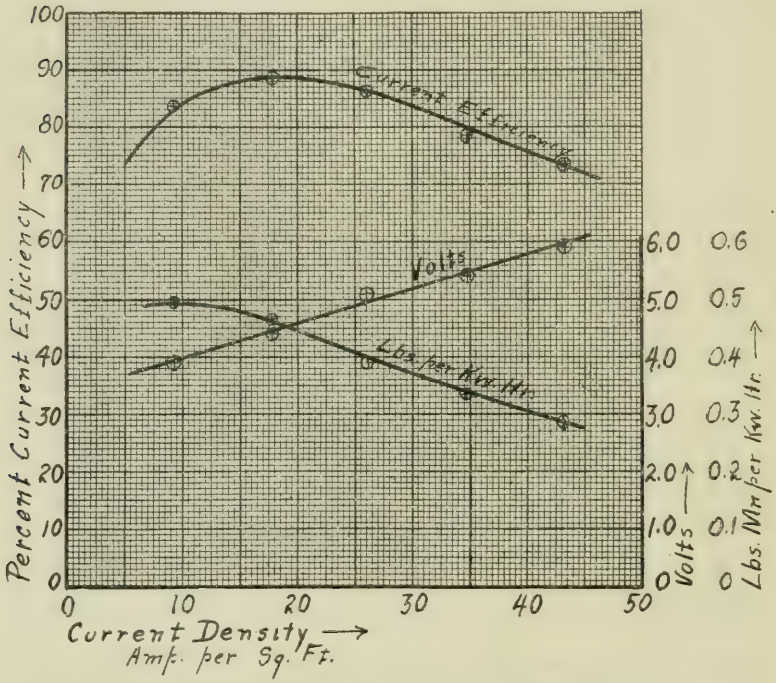

FIG. 1. Deposition of Mn at Cathode. Solution—Neutral Molal $MnSO_4$. Temperature—23° C. Effect of Increasing Current Density.

success, although in a few cases minor improvement was noted. A rise of temperature has deleterious effect, as described later, but a lowering of temperature even to approximately zero does not materially better the nature of deposit. It may be possible to obtain a reguline deposit of manganese, but the second difficulty is more serious.

(*B*) This is, of course, exactly as with zinc, the question of the effect of building up of acid in the solution. Unlike zinc, however, manganese in the pure electrolytic form will give a distinct

liberation of gaseous hydrogen even with ordinary tap water, and extremely dilute acids dissolve it easily, with vigorous evolution of hydrogen. Moreover, manganese solutions are easily hydrolyzed in air, because of the tendency for the manganese to oxidize according to the reaction,

$$2\ Mn^{++} + 2H_2O + O = \underset{(Mn_2O_3)}{Mn\ MnO_3} + 4H^+$$

This reaction, evidenced by the precipitation of manganese manganite (Mn_2O_3), is apparent in strong solutions in a few hours on exposure of a fresh solution to the air. That it is of serious importance with respect to the electrolysis is shown by the fact that an old solution, made up with tap water and allowed to stand two days, showed on electrolysis only 28 percent deposition efficiency, whereas a fresh solution of the same strength gave 85 percent.

Fig. 2 shows the effect of acidity on the manganese deposition current efficiency. It will be noted that only 0.36 percent free acidity is sufficient to entirely prevent the deposition of manganese, the efficiency dropping very rapidly.

Now, during the electrolysis the sulphuric acid builds up very rapidly, due to the reaction at both cathode and anode. It is easily calculable that each 0.01 percent of manganese deposited at the cathode will produce an increase of acidity of 0.035 percent, which corresponds to a decrease of efficiency of about 3 percent. There are at least three reasons why the neutralization of the increasing acidity is of great practical difficulty:

(*1*) Using manganese as the base for neutralization, it is apparent from the above behavior of hydrolyzed solutions that the amount of acid in equilibrium with the base and air, or with the base and the still worse oxidizing conditions at the anode, will be sufficient to prevent even fair current efficiencies from being obtained.

(*2*) The use of a slightly soluble foreign base, such as lime, is undesirable from many points of view, chief of which are the loss of manganese due to the formation of calcium manganites, the precipitation of calcium sulphate, loss of the acid radicle combined with calcium, difficulty of ensuring correct neutrality, and general complication of the electrolyte purification.

(3) The use of other bases, such as soluble alkalies, seems impracticable because of the cost of the chemical, loss of acid radicle, fouling of solution, etc.

In view of the above, the electrolytic deposition of manganese at the cathode does not seem to offer as much prospect of success as the anodic deposition as dioxide.

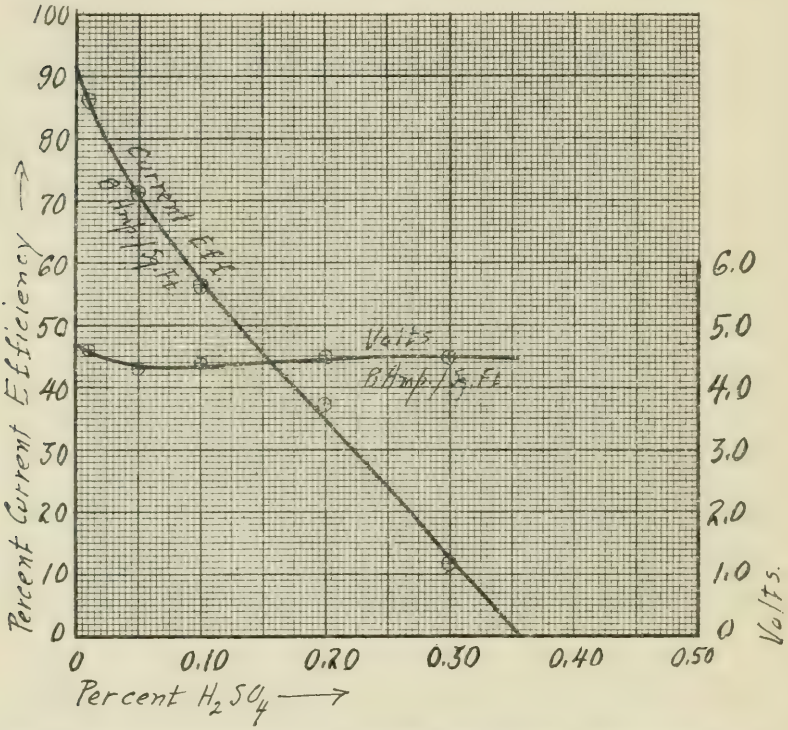

FIG. 2. Deposition of Mn at Cathode. Solution—Molal $MnSO_4$. Temperature—22° C. Effect of Acidity.

PART II.

DEPOSITION OF MnO_2 AT THE ANODE FROM MANGANESE SULPHATE SOLUTIONS.

The theoretical voltage for molal solution, compared to hydrogen, for the reaction $Mn^{++} \mid MnO_2$ is, as above given, — 1.35 volts. The maximum attainable deposition is, therefore, for the cell $H_2 \mid H_2SO_4 \mid MnSO_4 \mid MnO_2$, 2.56 lb. MnO_2 per K.W. hr.

Fig. 3 shows the effect of varying concentrations of manganese sulphate solutions on the current efficiency and voltage in neutral solutions. It is apparent that for moderately concentrated solutions, say over 5 percent $MnSO_4$, the values are approximately constant. The voltages for various current densities are given; the efficiency, however, only for the low value of 3.5 amperes per

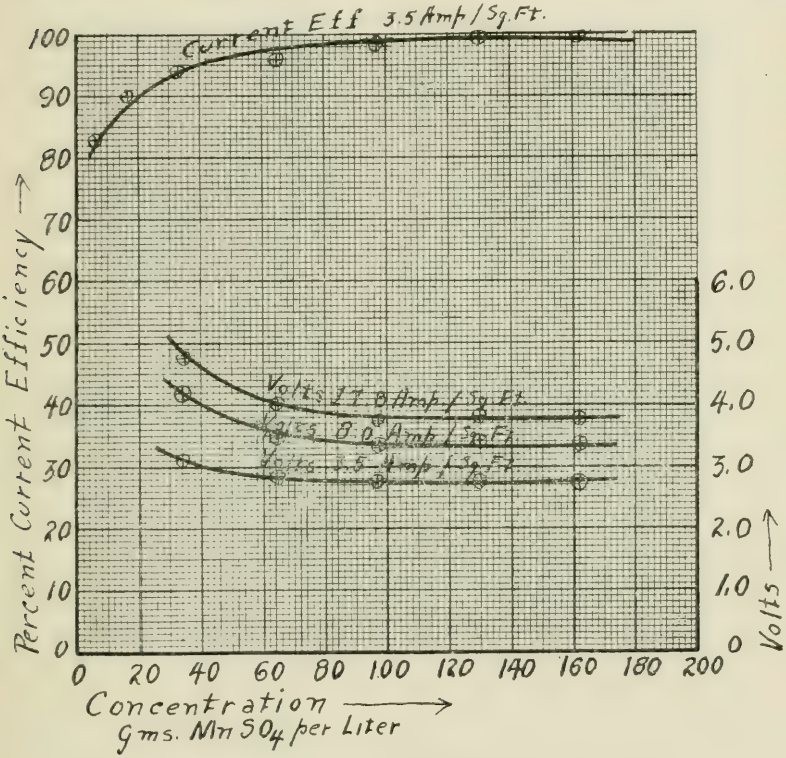
Current Eff 3.5 Amp / Sq. Ft.
Volts 7.7 Amp / Sq. Ft.
Volts 5.0 Amp / Sq. Ft.
Volts 3.5 Amp / Sq. Ft.
Percent Current Efficiency →
Volts →
Concentration →
Gms. MnSO4 per Liter
0 10 20 30 40 50 60 70 80 90 100
0 1.0 2.0 3.0 4.0 5.0 6.0
0 20 40 60 80 100 120 140 160 180 200

FIG. 3. Deposition of MnO_2 at Anode. Temperature—23° C. Effect of Concentration in Neutral Solutions.

sq. ft. (38.5 per sq. meter). At higher current densities the deposit becomes increasingly loose and powdery, and is split off by slight amounts of oxygen developed at the electrode surface. It was noted, however, that as the acidity builds up, due to separation of MnO_2, the deposit is markedly more dense and coherent, but unfortunately, as in Fig. 4, the loss in current efficiency is considerable with only moderate amounts of acid, and the current

density may accordingly not be appreciably increased without stripping of deposit, due to the co-evolution of oxygen.

The humps in the efficiency curves of Fig. 4 seem to indicate the presence in strong solutions of an acid salt.

The rapid decrease of efficiency of deposition, due to increase of acidity, although it was not of the same serious nature as the

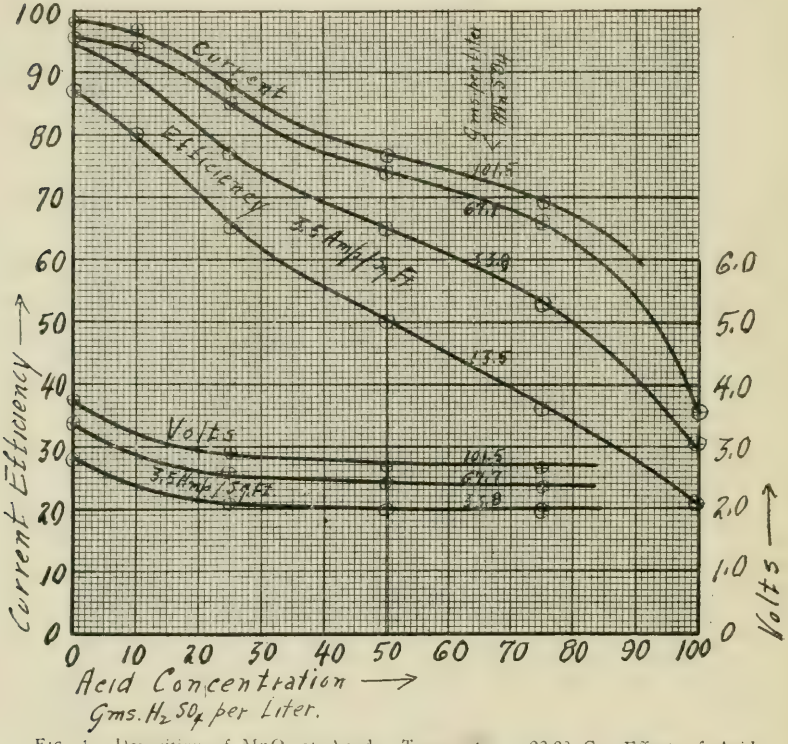

FIG. 4. Deposition of MnO_2 at Anode. Temperature—22.8° C. Effect of Acid in Various Concentrations of Solution.

difficulties encountered in the deposition of manganese at the cathode, constituted, nevertheless, a serious problem, particularly as only very low-current densities could be used. The difficulties rather unexpectedly disappeared when the temperature was increased to 65°-75° Centigrade, a result not obviously predictable from theoretical considerations.

The current efficiency of manganese deposition at the cathode is unfavorably affected by increase of temperature, so that at

60° C. efficiencies of only 20-30 percent are obtainable in solutions normally giving 80-90 percent. The reason for this is the increased hydrolysis at the higher temperature, resulting in larger amounts of free acid (see above). At the anode, however, an altogether different state of affairs exists. The formation of MnO_2 is not a direct deposition, but the result of a secondary

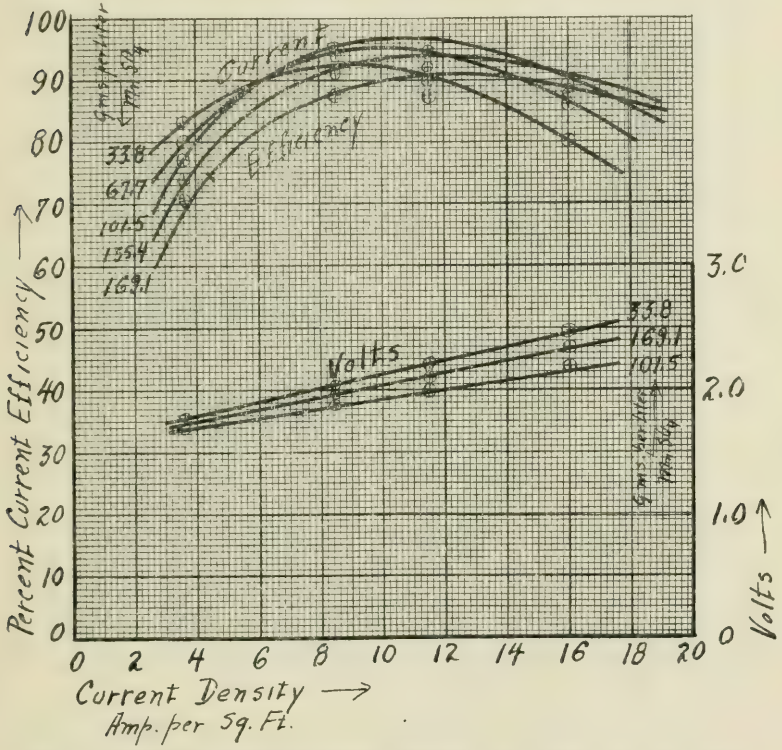

FIG. 5. Deposition of MnO_2 at Anode. Solutions—150 Grams per Liter H_2SO_4. Temperature—73° C. Effect of Increasing Current Densities on Solutions of Several Concentrations.

reaction, which will be discussed later. This reaction is markedly accelerated in speed and completeness by even moderate rises in temperature.

It was also found that at 65°-75° all trouble with the character of deposit ceased, and the decrease of current efficiency by increased acidity is practically negligible. The deposit is now a black, dense, varnish-like coating with sub-metallic luster, and

often exhibits iridescence. It consists of practically pure hydrated manganese dioxide when deposited from acid solutions, but contains some lower oxides (Mn_2O_3) when deposited from more neutral solutions. The current density may now be increased to 25 amp. per sq. ft. (275 per sq. m.), or even higher with graphite anodes, and a good deposit still secured.

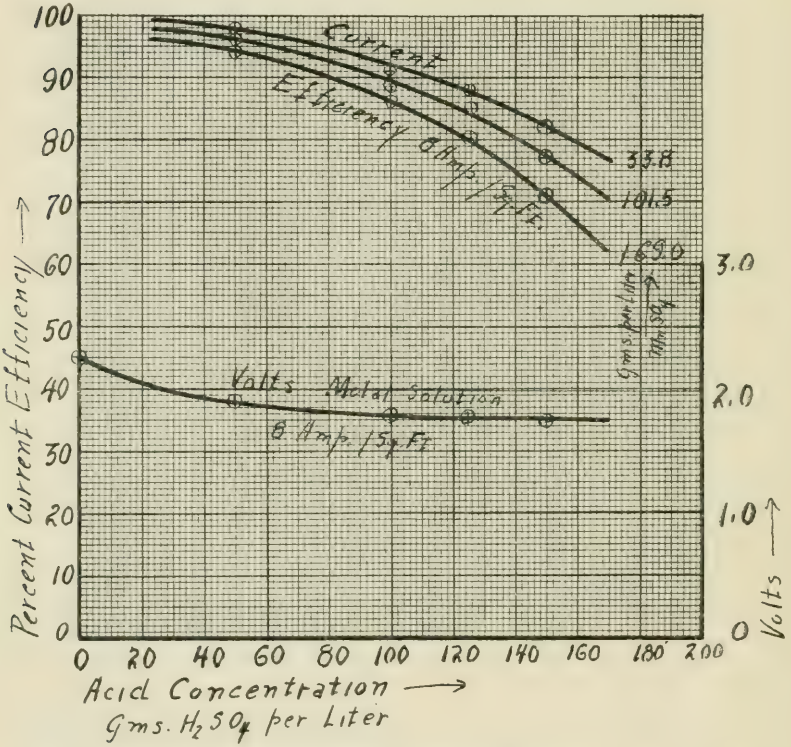

FIG. 6. Deposition of MnO_2 at Anode. Temperature—70-75° C. Effect of Acid in Several Concentrations of Solution.

Figs. 5 and 6 show the effects of various variables at 70°-75° C. It will be noted that a maximum efficiency is obtained at 8-15 amp. per sq. ft. (88-165 per sq. m.) current density, and that free acid now produces only slight fall of efficiency, even in strengths up to 15-20 percent H_2SO_4. The voltage, moreover, comes much closer to the theoretical figure, 1.55 (Fig. 5, intercept with ordinate axis) compared to 1.35.

The effect of continuous operation of a cell

$$H_2 \mid H_2SO_4 \mid MnSO_4 \mid MnO_2$$

is shown in Fig. 7. It is quite possible to obtain 1.5-2.0 lb. (0.7-0.9 kg.) of MnO_2 per K.W. hr.

Part III.

Theory of deposition of MnO_2 at the anode.

In neutral solutions, particularly at low temperatures, it is possible to get an amount of manganese deposited at the anode which when all figured as MnO_2 corresponds to from 100-130 percent of the theoretical. When the actual MnO_2, however, is determined chemically as MnO_2, values slightly less than 100 percent are invariably obtained. This clearly indicates that the hydrated MnO_2 combines with or carries down with it the lower oxide Mn_2O_3. In acid solutions, as would be expected, pure MnO_2 only is obtained. The reactions taking place are, therefore, in all probability

$$Mn^{++} + 2\ominus = Mn^{++++} \qquad (1)$$

The quadrivalent Mn is, however, easily and completely hydrolyzed

$$Mn^{++++} + 3HOH = H_2MnO_3 + 4H^+ \qquad (2)$$

In acid solution this is deposited as hydrated MnO_2. In neutral solutions, however,

$$Mn^{++} + H_2MnO_3 \leftrightarrows \underset{Mn\ MnO_3}{(Mn_2O_3)} + 2H^+ \qquad (3)$$

occurs to some extent.

Reactions *1* and *2* are complete reactions in the directions indicated, but *3* is reversible, depending on the acidity, for manganic acid is a weak acid. Thus, warm and fairly strong acid solutions will easily break up the Mn MnO_3, corresponding to the reversal of the reaction as written. The reason why it is possible to get more than 100 percent calculating *all* the manganese as MnO_2 in neutral solutions, is consequently evident.

Also, in cold solutions, as stated above, the peroxide tends to form throughout the solution, or at least some little distance away

from the anode. Moreover, a dark pink to violet color can be seen on looking at the anode, particularly in a sideways direction, corresponding no doubt to the higher valence manganese salts.

Whereas reaction *1*, in accordance with Faraday's law, should not be affected by heat except in so far as the concentration of Mn^{++} ions are changed thereby, reaction *2*, being a pure hydrolytic chemical reaction, should have its velocity increased approxi-

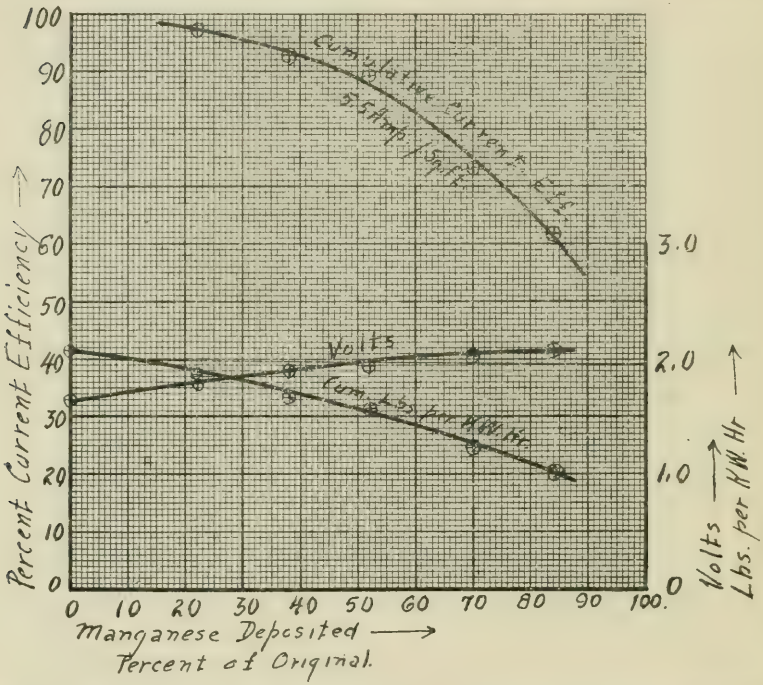

FIG. 7. MnO_2 | H_2 Cell, Continuous Operation. Solution to Start—135.4 Grams per Liter $MnSO_4$, 100 Grams per Liter H_2SO_4. Average Temperature—76° C.

mately 2.5 times for each 10° Centigrade. Thus, heating the solution has beneficial effects for two reasons:

(*a*) It increases the speed of hydrolysis so that the manganic solutions do not have time to diffuse away from the electrode before being decomposed, and it is then possible to build up a dense, coherent deposit;

(*b*) The rapid breaking up of the manganic salts prevents further oxidation resulting in oxygen being formed, and consequently

lower efficiency of deposition would result at low temperatures.

The acid also tends to accelerate the deposition according to reaction *2*, because H_2MnO_3, being a weak acid, should be less dissociated in very acid solutions.

The above explanation of the action of heat and acid are seen to be in full agreement with the above reactions.

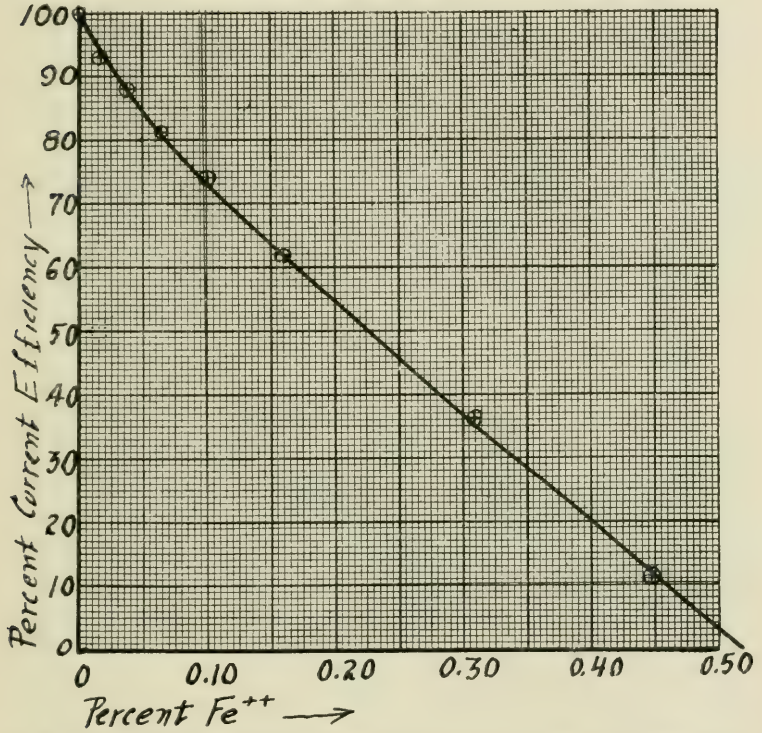

FIG. 8. Effect of Ferrous Iron on Deposition of MnO_2 at Anode. Solution—101.5 Grams $MnSO_4$/Liter, 10 Percent H_2SO_4. Temperature—70-75° C.

PART IV.

EFFECT OF IMPURITIES ON DEPOSITION OF MnO_2 AT THE ANODE.

In any practical process of concentration by electrochemical means, there will be two impurities present in the electrolyte which will interfere with the formation of MnO_2.

The first of these is ferrous iron. In acid solutions ferrous iron will be immediately oxidized by MnO_2. This may result in seri-

ous loss in efficiency. Fig. 8 shows the rapid decrease of current efficiency due to small amounts of ferrous iron, 0.52 percent being approximately sufficient to prevent entirely the formation of MnO_2. The cell now really becomes $Fe^{+++} \rightarrow Fe^{++}$ at the cathode, $Fe^{++} \rightarrow Fe^{+++}$ at the anode.

In using sulphur dioxide to leach peroxide ores, some complex sulphur compounds are always formed besides the ordinary sulphate. They are essentially thionates

$$MnO_2 + SO_2 = MnSO_4$$
$$MnO_2 + 2SO_2 = MnS_2O_6$$

The presence of these also lowers the current efficiency at the anode. In a typical leach liquor, 79 percent deposition efficiency was found, whereas a solution of pure salt of the same concentration normally gave 98 percent, the decreased efficiency being due to the thionates present.

Thionates also cause trouble at the cathode, since they are reduced there to sulphur, or hydrogen sulphide, causing rather serious fouling of the electrolyte.

It is possible to eliminate practically the effect of these two impurities, but this is more properly the problem of the working out of a commercial method. The purpose of the present paper has been merely to indicate the possibilities of the electrochemical separation of manganese, and to furnish some idea of the various factors entering into the problem.

All of the work done indicates that a method of electrolytic precipitation is practicable for the manufacture of high-grade manganese dioxide, and commercial operation might be possible on a comparatively small scale under favorable conditions at present, or even decidedly lower prices. The character of the deposit made under certain conditions is also highly desirable for some uses, and competition at slightly higher prices than for natural products should be possible.

Summary of Results.

(*A*)

1. Mn may be deposited at the cathode, from neutral solutions with high-current efficiency, from 80-90 percent, and at voltages from 3 volts up.

2. The effect of increase of acidity is practically to prevent the deposition of Mn at a concentration of 0.36 percent free H_2SO_4.

3. The deposit is powdery, and ordinary expedients for improving deposition do not give better results to any great extent.

(*B*)

1. MnO_2 may be deposited at the anode at nearly 100 percent efficiency.

2. The effect of acid is to decrease the efficiency in cold solutions, but on heating to 65°-75° C. there is very much less effect.

3. MnO_2 may be deposited from warm acid solutions containing more than 5 percent $MnSO_4$ in the form of a dense, black, lustrous film, at current densities up to 25 amp. per sq. ft. (275 per sq. m.) with very high deposition efficiency.

4. Impurities which are reducing agents cause a decrease in current efficiency in proportion to the amount present.

Appendix.

Chemical methods, etc.

For the deposition of elementary manganese at the cathode, either iron, copper or platinum cathodes were used, with graphite anode. For the determination of ampere efficiency the manganese was dissolved in dilute sulphuric acid, an aliquot part taken and analyzed by the Volhard method. Different kinds of cathodes gave approximately identical results.

For anodic determinations, graphite or platinum anodes were used for the determination of current efficiency, except in the case of continuous electrolysis. In the results shown in Fig. 7, copper cathodes and graphite anodes were used, and the MnO_2 deposited determined by analysis of samples of the electrolyte. In most of the other work the MnO_2 deposit on platinum was ignited and weighed as Mn_3O_4, or chemically determined as MnO_2 by solution in standard ferrous sulphate and titration with permanganate. The two methods give identical results with pure MnO_2, but when a deposit contains Mn_2O_3, for example one from neutral solution, the chemical method must be used.

Nothing much has been said regarding the types of electrodes. Platinum is, of course, entirely unsuited to all but laboratory

work, but graphite may be used equally successfully, or even carbon. The deposition of MnO_2 on a graphite or carbon anode may be carried on without any serious disintegration of the electrode, unless excessively high current densities, of 30 or more amp. per sq. ft. (330 per sq. m.), are used. Voltages are approximately the same with graphite as with platinum.

The thickness of deposit is of some importance in making measurements of current density. Since the electrical conductivity of the deposited dioxide is lower than that of the electrode material in most cases, there is some tendency for concentration of current flow lines, and possible gassing with its attendant stripping of the film of oxide. This is not of serious practical importance, but for the present measurements care was taken to secure thin, uniform deposits. The results, therefore, represent the best conditions of deposition.

The electrodes were spaced 1 inch (2.5 cm.) apart in all cases.

DISCUSSION.

C. G. MAIER: The first two plates are merely graphite anodes on which a thin coating of manganese dioxide has been plated, and the efficiency has been in the neighborhood of 100 percent. You will notice that that deposit is not very coherent; it is apt to crack. It can be made in coherent form, and to show you that, I have two small samples here. The deposit shows very fine iridescence and has been plated out for quite some time and is a permanent deposit. It is not sealed up in order to preserve it from cracking in the atmosphere, but merely to keep it clean and safe. The rest of the samples are merely flakes of manganese dioxide produced in various forms of fineness, which can be done by variation in current density, etc. You all know about the manganese problem, and although the paper tonight may seem to have a rather formidable title, it is nevertheless true that the electrolysis of manganese sulphate solutions has a certain practical interest. The reason for this is that one easy, and, I believe, practical method of getting manganese from low-grade

ores (which perhaps unfortunately constitute a rather large percentage of our native supply) is to dissolve them to an aqueous pulp by means of sulphur dioxide or perhaps some sulphuric acid. This may be done with very good recovery and the resulting product is essentially manganese sulphate solution.

When you electrolyze manganese sulphate, you of course have the two conditions at the cathode and the anode. At the cathode you can get in pure neutral solutions a very decent deposit, as far as current efficiency is concerned, of metallic manganese, but this metallic manganese is very active, and will react with practically pure water to give a distinct evolution of hydrogen gas; that is, a very small concentration of hydrogen ions will dissolve elementary manganese. That is the reason why you cannot make the cathodic deposition of manganese a practical process. A neutral solution of manganese in equilibrium with the oxidizing condition which necessarily exists at some place in the electrolytic cell, always contains sufficient acid due to hydrolysis to practically prevent any efficient deposition. So, although you can precipitate cathodic manganese in a perfectly neutral solution, it seems probable that the best way of getting the manganese out of sulphate solutions by electrolysis is to deposit it at the anode. This is not entirely a new method, as it has been known for a long time that it could be deposited at the anode as dioxide. The point was to find out just what conditions were best and what was the best current efficiency which could be obtained. We found when we first started out, that although in neutral solutions you could begin with practically 100 percent efficiency, the solution built up in acid quite rapidly. Under those conditions the current efficiency decreased and the deposit was not very coherent; it was powdery and dropped off in a very fine form. The really new thing in the paper is that we have found that the action of heat entirely prevents the incoherent form of deposits, and also almost entirely prevents the effect of acid reducing the current efficiency of deposition. The deposit under the acid conditions is identical with those samples, which were made in solutions containing perhaps about 10 percent acid. I might say you can start out with a fairly strong solution of manganese sulphate, and deposit manganese until nearly all is electrolyzed out, leaving only a solution of sulphuric acid containing a few tenths percent

of manganese. This is very interesting. The pounds per kilowatt hour is a very decent figure; you can get two or two and a half pounds per kilowatt hour by this process.

W. A. ERNST[1]: I would like to ask if that method was applied to a low-grade ore, say 33 percent manganese?

C. G. MAIER: It certainly would apply to a low-grade ore of 33 percent manganese. If it is in the form of dioxide you can recover 90 percent of the manganese without much trouble.

MR. ERNST: I happen to know a few acres that seem to be strewn as if a hail storm had struck it, but I have not been able to discover a well-defined vein. In Georgia I know of a vein high in silica that contains 33 percent of metallic manganese.

C. G. MAIER: As far as the leaching of manganese is concerned that will work on practically any oxide, and particularly on dioxide ores. After you get manganese sulphate, you have the choice of two methods of procedure. First there is the electrolytic method; or it is also possible to treat the manganese sulphate which we obtain by leaching by chemical, or I might say, metallurgical methods, which furnishes a product much more suitable for ferrous alloy work than this manganese dioxide product. This electrolytic product is in the neighborhood of 80 or 90 percent of MnO; that is, it is a hydrated form of manganese dioxide, but you can obtain by this other method a product containing 65 to 68 percent of metallic manganese, and I should be glad to talk to any one who is interested in it.

C. G. FINK[2]: A few weeks ago I saw a note in Iron Age on the experiments of the Anaconda Copper Company on manganese from rhodochrosite.

Jos. W. RICHARDS[3]: I have been informed that that company had manganese in their Butte mines, but it never paid them to get it out because it cost more to get it out than it was worth. But in the present emergency and shortage of manganese, the company is getting out all the manganese it can, and is already shipping rhodochrosite East to the ferro-manganese furnace reduction plant at Anniston. This is being done almost wholly from a patriotic motive, as it does not commercially pay them to do it.

[1] Chemist, Coosa Portland Cement Co., Ragland, Ala.
[2] Head of Laboratories, Chile Exploration Co., New York City.
[3] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.

THEODORE SWANN[1]: The Southern Manganese Corporation received the first three car loads of rhodochrosite which the Anaconda Copper Co. sent. We invited their engineers to be present. We tried using the ore both roasted and unroasted, and found the unroasted ore more satisfactory. However, we are not satisfied but what we can later use the roasted. Four of our furnaces are running on rhodochrosite. We are getting 30,000 tons which will run 35 to 38 percent manganese, and only 6 to 8 percent silica. We are mixing that ore, for commercial reasons, with the high iron ore that we buy in Georgia and Tennessee, which mixture runs about one to eight; that is, we are using about one-third of the high iron ore. The first time that we used straight rhodochrosite we had difficulty with the first few taps because we were making 83 and 84 percent manganese, which was a little too good, and we had to add iron to bring it down. We will arrange tomorrow for you to see the rhodochrosite and see how it works on the furnaces. I might say in reference to the roasted ore, that we had one roasted part of the charge and two unroasted parts. When you roast the ore, it comes up to about 54 percent manganese. When you use the same burden of coal and marble you do not get the right reaction. We lost too great an amount of manganese by volatilization. However, we hope to burn our marble first, which we use incidentally for flux. It is very white, and comes from a quarry nearby. We are working out a process of using three predigested portions in the charge, and hope to get very great efficiency if we work that out.

JOS. W. RICHARDS: I would like to ask the author whether he has made any experiments which would show that the deposition of manganese dioxide on the anode may possibly give an anode unattackable in the solutions from which oxygen is being generated; that is, whether the anode can be thus preserved by a coat of manganese dioxide?

C. G. MAIER: I think the disintegration of anode is usually due to the plating out of oxygen. If you plate out oxygen, I believe you will eventually disintegrate your anode. Of course this manganese dioxide is a conductor of electricity, but not nearly so good a conductor as graphite. If you use a thin film of

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MnO_2 on the graphite anode, the chances are that cracks will develop and you will plate out oxygen on your graphite in preference to the less conductive oxide and the anode will go; so I do not believe that MnO_2 will act as the perfect insoluble anode we are all looking for.

C. G. FINK: Have you tried alkaline solutions with an entirely different object in view, that is, for the production of sodium permanganate which, as we know, is also in great demand at the present time by the War Department?

C. G. MAIER: I do not think we have done anything along that particular line. We have thought of a very interesting solution, but we have not gone very far in regard to its application.

C. G. FINK: I should think it would well repay you to carry out experiments along the line of producing permanganate.

C. G. MAIER: I think this work has rather opened up other lines; if one has a supply of manganese dioxide which is practically chemically pure, many of the difficulties in the manufacture of permanganates are eliminated.

C. G. MAIER (*Communicated*): The electrolytic behavior of manganese at the anode has considerable interest entirely aside from the practical utilization of low-grade manganese ores. This is particularly true in regard to the line indicated by Dr. Richards' question. While it is true that a carbon electrode covered with a film of manganese dioxide is not a practical solution of the anode problem, we should realize that the deposition of MnO_2 at the anode enables us to produce the following important results:

(1) The inhibition of oxygen formation at the anode resulting in two important conditions: (*a*) the fact that it is possible to produce MnO_2 at the anode at nearly 100 percent current efficiency, necessarily means that manganese sulphate in solution will, under certain circumstances, function as an anodic depolarizer; (*b*) since the manganese dioxide, which may be deposited from certain sulphate solutions prevents the formation of oxygen in proportion to the extent to which its current efficiency approaches 100 percent, it is true that the presence of manganese sulphate also must act specifically as a medium for prevention of disintegration.

(2) The concentration of oxygen or its equivalent oxydizing power into a solid deposit at the anode, gives us a means of saving and possibly re-using the oxydizing power of the anode, which might ordinarily be lost in case oxygen were evolved.

This aspect of the work is not altogether new, inasmuch as the beneficial effects of manganese in the electrolytic deposition of zinc are well known and utilized. It must be evident, however, that the conceivable applications to electrolytic processes in general may be ultimately of considerable importance.

Paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

THE EFFECT OF IRON SULPHATE IN THE ELECTROLYTIC PRECIPITATION OF COPPER FROM SULPHATE SOLUTION WITH INSOLUBLE LEAD ANODES.[1]

By Edward F. Kern.[2]

Abstract.

Solutions of copper sulphate containing varying quantities of iron sulphate were electrolyzed with insoluble lead anodes at different temperatures and with different current densities, in order to determine the effect of the iron salt present on the current efficiency of copper deposition at the cathode. The lowering of efficiency was found due to adduction of ferrous sulphate to ferric sulphate at the anode, and reduction of ferric sulphate to ferrous sulphate at the cathode. The results are given quantitatively. [J. W. R.]

The effect of iron salts in the electrolyte of an oxy-hydrogen coulometer was reported by Elbs in Zeit. Elektrochem. (1901), **7**, 261. He found that the presence of iron sulphate in the sulphuric acid electrolyte of an oxy-hydrogen coulometer having platinum electrodes decreased materially the amount of gas evolved. His deductions from the experiments were that elements which have two different valences should not be in the electrolyte of an oxy-hydrogen coulometer, as the successive reduction of the cations at the cathode and their adduction at the anode affects the liberation of the gases. In the case of iron salts, ferric ions are reduced to the ferrous condition at the cathode, and ferrous ions are oxidized to the ferric state at the anode, so that the actual amount of gases evolved depends upon the rate of diffusion of ferrous

[1] Manuscript received March 18, 1918.
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salts to the anode and ferric salts to the cathode, and also upon the current density as well as upon the concentration of the iron salts in the electrolyte. The effect of low current density, when iron sulphate is in the electrolyte, is to cause a larger decrease in the amount of gases liberated, and the larger the amount of iron present the greater the decrease of gas liberated.

Schwab and Baum reported in the Journal of Physical Chemistry (1903), **7**, 516, that the presence of iron sulphate in copper sulphate electrolytes did not cause a reduction in the current efficiency when a copper anode is used.

Bell repeated the experiments of Elbs, and those of Schwab and Baum, and confirmed the results of the original experiments. (Journal of Physical Chemistry (1903), **7**, 654.) He also ran an experiment in order to determine the effect of iron sulphate in a copper coulometer. Three cells were connected in series; the first (cell A) was a copper coulometer having a copper anode; the second (cell B) was a copper coulometer with copper electrodes and with iron sulphate in the electrolyte; the third (cell C) was a copper coulometer with a platinum anode and with iron sulphate in the electrolyte. The electrolytes had the following composition: that in cell A contained 150 grams of $CuSO_4.5H_2O$, 50 grams of H_2SO_4, and 50 grams of ethyl alcohol per liter; that in cells B and C was of same composition plus an addition of 50 grams of $FeSO_4.7H_2O$ per liter. The results of Bell's experiments are:

Amperes per sq. dm.	Coulometer, Cell A. Cathode Gain. 100 Percent Efficiency Grams	Cell B.		Cell C.	
		Cathode Gain Grams	Current Efficiency Percent	Cathode Gain Grams	Current Efficiency Percent
1.0	1.794	1.781	99.3	1.642	91.5
0.5	1.185	1.182	99.7	0.997	84.1
0.2	1.543	1.533	99.4	1.045	69.9

The current efficiency of the copper coulometer (cell A) was 100 percent efficiency; that of cell B, which contained a copper anode and iron sulphate in the electrolyte, was over 99 percent irrespective of the current density, showing that the presence of

the iron has no effect when a copper anode is used; but the current efficiency of cell C which contained a platinum anode and iron in the electrolyte, was low due to the presence of the iron, and the lower the current density the lower the current efficiency.

EXPERIMENTAL PART.

The experiments upon which this article is based were conducted in the electro-metallurgical laboratory of the School of Mines of Columbia University by Mr. Hsiang Tsai. The experiments were conducted with the idea of obtaining some data upon the effect of iron salts in the electrolytic precipitation of copper from solutions obtained by the leaching of copper ores with dilute sulphuric acid.

In the treatment of copper ores by hydro-electrolytic methods, not only is copper dissolved, but other metals are also dissolved. In practice it has been found that iron under certain conditions causes the copper to deposit on the cathode as a non-adherent precipitate, and also that the iron in solution causes a great decrease in current efficiency, especially when the electrolysis is conducted by operating with a higher current density at the cathode than at the anode.

The solutions which were electrolyzed during each of the 36 experiments were prepared so as to contain at the start 2.5 grams of copper and 6 grams of free sulphuric acid per 100 cc., and iron present as sulphate (ferrous at start) in amounts of 0, 0.75, 1.50, and 3.00 grams per 100 cc. of electrolyte.

The efficiency of the experiments was determined by running the cells in series with a copper coulometer, the electrolyte of which was prepared so as to contain 150 grams of $CuSO_4.5H_2O$, 50 cc. of concentrated sulphuric acid (sp. gr. 1.84), 65 cc. of ethyl alcohol (sp. gr. 0.79) per liter, using distilled water as the solvent.

The anodes used in the experimental cells were sheet lead of such surface area as to give the desired ratio of current density at anode to that at the cathode, and the cathodes in each cell were sheet copper. The circulation of the electrolytes were maintained by means of small glass propellers driven by a small electric motor at such a speed as to prevent segregation of the constituents of the electrolyte. In order to prevent evaporation from

the cells, which were run for more than a day, a thin layer of dynamo oil was poured on the surface of the electrolyte. The cells, which were kept at approximately 50° C., were heated on a sand bath, and the flame so adjusted that the temperature remained practically constant.

The records and the results of the experiments are given in Tables I to VI. The potential drop between anode and cathode, in all of the experiments, was between 1.8 and 2 volts.

SUMMARY OF RESULTS.

1. The presence of iron reduces the efficiency in the electrolytic precipitation of copper from sulphate solutions, when insoluble lead anodes are used. The higher the percentage of iron in the electrolyte, the lower is the current efficiency, and *vice versa*.

2. The smaller the amount of copper in the electrolyte, the greater is the reduction of current efficiency as the result of the presence of iron sulphate in the solution. At the beginning of the electrolysis the current efficiency is relatively higher, but as electrolysis is continued, the efficiency is progressively less, because the ferric ions which are produced at the anode are reduced to the ferrous condition when they come in contact with the copper cathode, dissolving a corresponding equivalent of copper. The more concentrated the electrolyte in ferric ions, the lower is the current efficiency. Continued electrolysis produces continued adduction at the anode of ferrous ions to ferric ions up to a certain concentration, after which the current efficiency does not drop so rapidly as it does when this concentration has not been reached.

3. When iron is present, a higher current efficiency is obtained by operating with a lower current density at the cathode than that at the anode; under these conditions the oxidizing effect at the anode is less, as the efficiency of the secondary reaction ($2FeSO_4 + H_2SO_4 + \frac{1}{2}O_2 \rightarrow Fe_2(SO_4)_3 + H_2O$) is lower. The higher the anode current density, as compared to the cathode current density, the greater the relative amount of oxygen that will be liberated at the anode, consequently the fewer ferric ions will be formed. By operating with a relatively higher current density at the cathode than at the anode, the current efficiency is

TABLE 1. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.			Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Percent Efficiency
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.	Ratio		Hrs.	Min.	Start	Finish			
1	0	2.50	1.50	5	5	1 to 1	50	23	30	64.85	73.85	9.00	10.99	81.9
	0	1.50	0.60	5	5	1 to 1	50	19	50	73.85	81.98	8.13	10.13	80.3
2	0.75	2.50	2.19	5	5	1 to 1	50	23	30	63.22	66.03	2.81	10.99	25.6
	0.75	2.19	1.12	5	5	1 to 1	50	48	10	66.03	76.46	10.43	43.75	23.8
3	1.50	2.50	2.23	5	5	1 to 1	50	23	30	66.63	69.03	2.40	10.99	21.8
	1.50	2.23	1.70	5	5	1 to 1	50	48	10	69.03	73.82	4.79	43.75	11.1
	1.50	1.70	1.89	5	5	1 to 1	50	19	50	73.82	72.16	—1.66	10.13	—16.4
4	3.00	2.50	2.19	5	5	1 to 1	50	23	30	73.73	76.30	2.57	10.99	23.4
	3.00	2.19	1.74	5	5	1 to 1	50	48	10	76.30	80.30	4.00	43.75	9.1
	3.00	1.74	2.08	5	5	1 to 1	50	19	50	80.30	77.27	—3.03	10.13	—29.9
5	0	2.50	1.05	7.5	5	1.5 to 1	20	24	10	99.15	112.16	13.01	15.96	81.5
	0	1.05	0.10	7.5	5	1.5 to 1	20	17	0	112.16	120.80	8.64	9.75	88.6
6	0.75	2.50	1.86	7.5	5	1.5 to 1	20	24	10	92.58	98.36	5.78	15.96	36.2
	0.75	1.86	1.56	7.5	5	1.5 to 1	20	17	0	98.36	101.10	2.74	9.75	28.1
7	1.50	2.50	1.92	7.5	5	1.5 to 1	20	24	10	102.43	107.68	5.25	15.96	32.2
	1.50	1.92	2.06	7.5	5	1.5 to 1	20	17	0	107.68	106.43	—1.25	9.75	—12.8
8	3.00	2.50	1.86	7.5	5	1.5 to 1	20	24	10	93.77	99.48	5.71	15.96	35.7
	3.00	1.86	2.06	7.5	5	1.5 to 1	20	17	0	99.48	97.75	—1.73	9.75	—17.7
9	0	2.50	1.36	10	5	2 to 1	50	19	38	81.98	92.77	10.79	12.80	84.3
	0	1.36	0.38	10	5	2 to 1	50	23	5	92.77	102.38	9.61	10.87	88.4

TABLE II. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.			Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Percent Efficiency
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.	Ratio		Hrs.	Min.	Start	Finish			
10	0.75	2.50	2.10	10	5	2 to 1	50	19	38	76.30	79.58	3.28	12.80	25.6
	0.75	2.10	2.03	10	5	2 to 1	50	23	5	79.58	80.17	0.59	10.87	5.4
	0.75	2.03	1.75	10	5	2 to 1	50	22	35	80.17	82.57	2.40	15.42	15.5
	0.75	1.75	1.44	10	5	2 to 1	50	23	15	82.57	85.02	2.45	16.66	14.7
11	1.50	2.50	2.26	10	5	2 to 1	50	19	38	72.16	74.26	2.10	12.80	16.4
	1.50	2.26	2.56	10	5	2 to 1	50	23	5	74.26	74.00	—0.26	10.87	—2.4
	1.50	2.56	2.41	10	5	2 to 1	50	22	35	74.00	75.18	1.18	15.42	7.6
	1.50	2.41	1.80	10	5	2 to 1	50	23	15	75.18	75.73	0.55	16.66	3.3
12	3.00	2.50	2.20	10	5	2 to 1	50	19	38	77.27	79.83	2.56	12.80	20.0
	3.00	2.20	2.28	10	5	2 to 1	50	23	5	79.83	79.34	—0.49	10.87	—4.5
	3.00	2.28	2.15	10	5	2 to 1	50	22	35	79.34	80.47	1.13	15.42	7.3
	3.00	2.15	2.09	10	5	2 to 1	50	23	15	80.47	81.06	0.59	16.66	3.5
13	0	2.50	1.37	20	5	4 to 1	20	17	45	119.58	129.44	9.86	10.20	96.7
	0	1.37	1.17	20	5	4 to 1	20	5	0	129.44	131.10	1.66	1.85	90.0
	0	1.17	0.23	20	5	4 to 1	20	19	45	131.10	139.65	8.55	9.39	91.0
14	0.75	2.50	2.00	20	5	4 to 1	20	17	45	101.75	106.50	4.75	10.20	46.6
	0.75	2.00	1.85	20	5	4 to 1	20	5	0	106.50	107.62	1.12	1.85	60.5
	0.75	1.85	1.36	20	5	4 to 1	20	21	10	107.62	111.92	4.30	12.04	35.7
	0.75	1.36	0.95	20	5	4 to 1	20	19	45	111.92	115.72	3.80	9.39	40.5
	0.75	0.95	0.55	20	5	4 to 1	20	30	0	115.72	122.18	6.46	15.93	40.5

TABLE III. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.			Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Percent Efficiency
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.	Ratio		Hrs.	Min.	Start	Finish			
15	1.50	2.50	2.07	20	5	4 to 1	20	17	45	106.55	110.45	3.90	10.20	38.2
	1.50	2.07	2.00	20	5	4 to 1	20	5	0	110.45	111.09	0.64	1.85	34.6
	1.50	2.00	1.84	20	5	4 to 1	20	21	10	111.09	112.55	1.46	12.04	12.1
	1.50	1.84	1.69	20	5	4 to 1	20	19	45	112.55	113.98	1.43	9.39	15.2
	1.50	1.69	1.50	20	5	4 to 1	20	30	0	113.98	115.70	1.72	15.93	10.8
16	3.00	2.50	2.04	20	5	4 to 1	20	17	45	97.94	102.14	4.20	10.20	41.2
	3.00	2.04	2.00	20	5	4 to 1	20	5	0	102.14	102.42	0.28	1.85	15.2
	3.00	2.00	1.87	20	5	4 to 1	20	21	10	102.42	103.53	1.11	12.04	9.2
	3.00	1.87	1.72	20	5	4 to 1	20	19	45	103.53	104.95	1.42	9.39	15.1
	3.00	1.72	1.57	20	5	4 to 1	20	30	0	104.95	106.25	1.30	15.93	8.1
17	0	2.50	1.13	20	5	4 to 1	50	25	0	139.18	152.48	13.30	14.62	91.0
	0	1.13	0.18	20	5	4 to 1	50	18	20	152.48	162.02	9.54	11.54	82.7
18	0.75	2.50	2.18	20	5	4 to 1	50	25	0	122.04	124.90	2.86	14.62	19.6
	0.75	2.18	2.00	20	5	4 to 1	50	18	20	124.90	126.53	1.63	11.54	14.3
	0.75	2.00	1.08	20	5	4 to 1	50	43	10	126.53	134.86	8.33	32.66	25.5
	0.75	1.08	0.18	20	5	4 to 1	50	50	40	134.86	142.95	8.09	39.08	20.7
19	1.50	2.50	2.21	20	5	4 to 1	50	25	0	115.70	118.32	2.62	14.62	18.0
	1.50	2.21	2.07	20	5	4 to 1	50	18	20	118.32	119.62	1.30	11.54	11.3
	1.50	2.07	1.49	20	5	4 to 1	50	43	10	119.62	124.78	5.16	32.66	15.8
	1.50	1.49	1.11	20	5	4 to 1	50	50	40	124.78	128.22	3.44	39.08	8.8

TABLE IV. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.		Ratio	Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Percent Efficiency
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.			Hrs.	Min.	Start	Finish			
20	3.00	2.50	2.30	20	5	4 to 1	50	25	1	105.25	107.07	1.82	14.62	12.4
	3.00	2.30	2.26	20	5	4 to 1	50	18	20	107.07	107.49	0.42	11.54	3.7
	3.00	2.26.	1.75	20	5	4 to 1	50	43	10	107.49	109.98	2.49	32.66	7.6
	3.00	1.75	1.45	20	5	4 to 1	50	50	40	109.98	112.63	2.65	39.08	6.8
21	0	2.50	0.33	10	10	1 to 1	50	19	25	159.52	178.99	19.47	20.46	95.0
22	0.75	2.50	1.69	10	10	1 to 1	50	19	25	142.93	150.22	7.29	20.46	35.6
	0.75	1.69	1.61	10	10	1 to 1	50	6	5	150.22	150.87	0.65	5.42	12.0
	0.75	1.61	0.80	10	10	1 to 1	50	19	45	150.87	158.22	7.35	20.47	35.9
	0.75	0.80	0.69	10	10	1 to 1	50	5	35	158.22	159.25	1.03	5.79	17.7
23	1.50	2.50	1.91	10	10	1 to 1	50	19	25	128.20	132.45	4.25	20.46	20.7
	1.50	1.91	1.93	10	10	1 to 1	50	6	5	132.45	132.38	—0.07	5.42	—1.3
	1.50	1.93	1.68	10	10	1 to 1	50	19	45	132.38	134.67	2.29	20.47	11.2
	1.50	1.68	1.75	10	10	1 to 1	50	5	35	134.67	134.03	—0.64	5.79	—11.0
	1.50	1.75	1.59	10	10	1 to 1	50	22	40	134.03	135.45	1.42	20.67	6.8
24	3.00	2.50	1.83	10	10	1 to 1	50	19	25	47.12	53.16	6.04	20.46	29.5
	3.00	1.83	1.81	10	10	1 to 1	50	6	5	53.16	53.35	0.19	5.42	3.5
	3.00	1.81	1.66	10	10	1 to 1	50	19	45	53.35	54.74	1.39	20.47	6.8
	3.00	1.66	1.68	10	10	1 to 1	50	5	35	54.74	54.57	—0.17	5.79	—2.9
	3.00	1.68	1.49	10	10	1 to 1	50	22	40	54.57	56.32	1.75	20.67	8.4
25	0	2.50	0.14	15	10	1.5 to 1	20	21	20	58.16	79.27	21.11	21.85	96.6

TABLE V. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.			Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Percent Efficiency
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.	Ratio		Hrs.	Min.	Start	Finish			
26	0.75	2.50	0.97	15	10	1.5 to 1	20	21	20	64.70	78.82	14.12	21.85	64.6
	0.75	0.97	0.77	15	10	1.5 to 1	20	2	0	78.82	80.24	1.42	3.31	43.0
	0.75	0.77	0.58	15	10	1.5 to 1	20	2	50	80.24	81.98	1.74	2.85	61.0
	0.75	0.58	0.35	15	10	1.5 to 1	20	6	29	81.98	84.00	2.02	4.13	48.9
27	1.50	2.50	1.16	15	10	1.5 to 1	20	21	20	60.67	72.70	12.03	21.85	55.0
	1.50	1.16	0.43	15	10	1.5 to 1	20	18	35	72.70	79.33	6.63	19.31	34.3
	1.50	0.43	0.34	15	10	1.5 to 1	20	2	50	79.33	80.21	0.88	2.85	30.9
	1.50	0.34	0.25	15	10	1.5 to 1	20	2	29	80.21	80.91	0.70	2.63	26.6
28	3.00	2.50	1.08	15	10	1.5 to 1	20	21	20	56.33	69.08	12.75	21.85	58.3
	3.00	1.08	0.48	15	10	1.5 to 1	20	18	35	69.08	73.61	4.53	19.31	23.4
	3.00	0.48	0.40	15	10	1.5 to 1	20	2	50	73.61	74.31	0.70	2.85	24.5
	3.00	0.40	0.30	15	10	1.5 to 1	20	4	39	74.31	76.08	1.77	6.49	27.3
29	0	2.50	1.78	20	20	1 to 1	50	2	50	49.83	56.38	6.55	6.64	98.6
	0	1.78	0.39	20	20	1 to 1	50	6	10	53.53	66.10	12.57	12.93	97.2
30	0.75	2.50	1.92	20	20	1 to 1	50	2	50	51.12	56.34	5.22	6.64	78.6
	0.75	1.92	1.00	20	20	1 to 1	50	6	10	51.91	59.57	7.66	12.93	59.2
	0.75	1.00	0.64	20	20	1 to 1	50	2	40	59.57	63.29	3.72	5.81	64.0

TABLE VI. *Electrolyte Contained 6 Grams Free H_2SO_4 per 100 cc. at Start.*

Run No.	Composition of Electrolyte			Current Density per Sq. Ft.			Approx. Temp. of Electrolyte, °C.	Time of Electrolysis		Weight of Cathode Grams		Copper Deposited Grams	Copper Deposited in the Coulombmeter Grams	Efficiency Percent
	Percent Fe as Sulphate	Percent Cu at Start	Percent Cu at Finish	Anode Amp.	Cathode Amp.	Ratio		Hrs.	Min.	Start	Finish			
31	1.50	2.50	1.97	20	20	1 to 1	50	2	50	48.40	53.21	4.81	6.64	72.4
	1.50	1.97	1.52	20	20	1 to 1	50	6	10	51.21	55.03	3.82	12.93	30.0
	1.50	1.52	1.27	20	20	1 to 1	50	2	40	55.03	57.26	2.23	5.81	38.3
	1.50	1.27	0.21	20	20	1 to 1	50	16	22	57.26	66.75	9.49	30.09	31.5
32	3.00	2.50	1.93	20	20	1 to 1	50	2	50	56.42	61.47	5.05	6.64	76.1
	3.00	1.93	1.39	20	20	1 to 1	50	6	10	61.47	66.25	4.78	12.93	37.0
	3.00	1.39	1.17	20	20	1 to 1	50	2	40	66.25	68.25	2.00	5.81	34.4
	3.00	1.17	0.56	20	20	1 to 1	50	16	22	68.25	73.75	5.50	30.09	18.2
33	0	2.50	0.25	30	20	1.5 to 1	20	8	0	77.99	100.61	22.62	24.19	93.5
34	0.75	2.50	0.42	30	20	1.5 to 1	20	11	25	83.66	104.93	21.27	35.15	60.5
35	1.50	2.50	0.53	30	20	1.5 to 1	20	11	25	80.71	100.94	20.23	35.15	57.5
36	3.00	2.50	0.76	30	20	1.5 to 1	20	11	25	76.07	94.24	18.17	35.15	51.7

lowered on account of the formation of ferric ions being accelerated; and, there being a greater concentration of ferric ions, the current efficiency is lowered by copper being dissolved from the cathode according to the reaction $Cu + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4$. The negative efficiencies were due to this reaction.

4. The effect of temperature upon the deposited copper is that smoother and purer copper is formed at 50° C. than at lower temperatures. If iron is in solution, the current efficiency is lowered by heating the electrolyte, as the formation of ferric ions at the anode is accelerated and the dissolving of copper from the cathode is relatively increased. The larger the amount of iron in the electrolyte, the greater is the lowering of the current efficiency at higher temperatures.

5. When no iron is present in the electrolyte, the copper may be almost completely removed, and the current efficiency remains very high, even though the copper in solution be reduced to as low as 0.2 gram per 100 cc. Higher current efficiencies are obtained when the current density at the cathode is between 10 and 20 amperes per square foot than when a current density of 5 amperes per square foot is run. When no iron is present, the current density at the anode has no effect upon the deposition of the copper, nor upon the current efficiency so long as there are sufficient copper ions to transfer the current.

6. Iron in the copper sulphate electrolyte causes the copper to deposit less smooth and less dense, irrespective of the ratio of current density at anode to that of cathode. It was seen that less adherent and less dense copper was deposited on the cathode from the electrolytes which contained iron than from electrolytes which contained no iron and which also contained far less copper.

7. The effect of the presence of iron in the electrolyte is to reduce the voltage required for the electrolysis. When no iron was present the potential drop between anode and cathode was approximately 2 volts; whereas when iron was present it was lower, in most cases being approximately 1.8 volt.

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DISCUSSION.

C. S. WITHERELL[1]: Dr. Kern's work was apparently done for the object of determining what deleterious effect iron would have in electrolytes as used in electrolytic copper refining. I have several criticisms to make with reference to this paper which I wish the author were here to explain. He starts out by giving a very brief description of an experiment he made with varying current densities, with pure copper sulphate solution. You will see this on page 132, also the same solution with ferrous sulphate added, electrolyzed with a copper anode, and the same solution with ferrous sulphate added, electrolyzed with a platinum anode. He states that to the first solution was added ethyl alcohol, 50 grams per liter. Of course this was done for the purpose of making the first cell a coulometer, and it would appear from the way he has expressed himself, that the subsequent solutions also had alcohol in them, but I cannot think he means that.

C. G. FINK[2]: It sounds that way.

C. S. WITHERELL: And even further on he leaves one in doubt as to whether he added alcohol to the subsequent solution, but I cannot think he did, because we do not use large quantities of alcohol in copper refinery electrolytes.

C. G. FINK: Not in the baths, no.

C. S. WITHERELL: Another mistake I believe occurs on page 134, at the bottom of the page, where he states that "by operating with a relatively higher current density at the cathode, the current efficiency is lowered." I think he means "relatively lower current density." That is probably merely a typographical error. The main criticism I wish to make is that he does not give us any figures as to the amount of ferric and ferrous iron in solution. The current efficiency is lowered mainly by two causes: first, by the re-solution of the cathode; second, in consequence of short circuits, which is due to rough copper. The first cause of course is the one to be considered in this article. The re-solution of cathodes in Dr. Kern's experiments is naturally due almost en-

[1] Metallurgical Engineer, Chile Exploration Co., New York City.
[2] Head of Laboratories, Chile Exploration Co., New York City.

tirely to ferric salt. The ferrous salt may play a rôle in making rougher copper and thereby indirectly lower the current efficiency, but if he is after the particular influence of the re-solution of the cathode, he must know the amount of iron in the ferric state. If you consider the results of his experiments on page 132, and look under Cell *C*, current efficiency, percent, and deduct each from 100, you will obtain the following figures: 8.5, 15.9, 30.1. You would expect that if the falling off of the current efficiency is due to the re-solution of the cathode, that the amount it fell off would be inversely proportional to the current density; in other words, the re-solution of the cathode takes place whether you are running the current through or not. Hence using the current as a divisor, that value must increase inversely as the current density. In other words, if you multiply current density by the figures I have just given you, you would expect to obtain a nearly constant quantity. This I have done. The first would be 8.5, the next would be 7.95, and the last would be 6.0. They are not quite constant; the higher the current density given, the higher is the dissolving effect; the lower the current density, the lower is that effect. But that is to be expected, because the higher the current density, the greater the ratio of the ferric iron to the ferrous iron in any given solution containing iron. That is, the oxidation effect is just that much more; in other words, the quantity of ferric salt is not constant, bringing out the point I just mentioned, that it was very important to have determined the amount of ferric salt. Furthermore, going over to his other experiments which are tabulated on pages 135, 136 and 137, the author apparently started out his solution in each case with all the iron in the ferrous state, carried on electrolysis, periodically removed the cathode and weighed it, put it back, continued the electrolysis, took it out again and weighed it, and so on, and obtained three or four results from each run. Therefore his first run, and first current efficiency, were determined starting with all ferrous iron. As he went on, ferric iron became higher. What I recommend he should have done to get valuable figures for copper refiners, would be to have run each determination for a period of time, until the ratio of the ferric to the ferrous salts became constant, then made a determination of the current efficiency at that point, giving us two valuable data for each iron

content; namely the ratio ferric to ferrous iron, and the efficiency at that ratio. If he had followed it out to that extent, this table would have been of more value, and I think also would have eliminated those somewhat erratic figures in the last column which do not plot to smooth curves.

Referring to page 141, conclusion No. 7; of course that resolves itself on the "presence of iron," but he should say "the effect of the presence of ferric and ferrous iron," and treat the ferric and the ferrous iron as two separate substances.

C. G. FINK: This problem of the effect of iron on the electrolysis of copper is rather complex and there are a number of us who are busily engaged on experiments along this line, but there is nothing definitely established as yet as far as I know. Perhaps some other gentleman present can tell us a little more.

J. L. YARDLEY[3]: According to my understanding at the Electrolytic Copper Plant at Ajo, Arizona, the solution as it enters the cell room, contains a combination of ferrous and ferric iron, the ferrous iron preponderating. The iron in the solution is changed as it passes through the cell room and, as it leaves, the ferric iron preponderates. Before the solution returns to the cell room it goes through reduction towers through which sulphur dioxide gas is passed, and is there changed again to the condition in which ferrous iron preponderates. This changing back and forth from one condition to the other is, therefore, a continuous process, and the bad effects in the cell room of having excessive ferric iron present in solution are largely eliminated.

C. G. FINK: Of course everyone familiar with the electrolytic determination of copper appreciates the necessity of removing iron when large quantities of it are present.

E. F. KERN (*Communicated*): Mr. Witherell and Dr. Fink failed to see that "Insoluble Lead Anodes" were used in conducting the experiments. I cannot understand why they should overlook this important statement of the subject. The purpose of the work was to find out what effect iron sulphate has upon the electrolytic precipitation of copper from copper sulphate solutions by the use of insoluble lead anodes, and also under what

[3] General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

conditions of current densities and temperature of electrolyte the effect of the presence of the iron sulphate in the copper sulphate solution is the most detrimental. I cannot understand how they should have had the idea that the experiments "were done for the object of determining what deleterious effect iron would have in the electrolytes as used in electrolytic copper refining." The first two paragraphs under Experimental Part state exactly the object of undertaking the experiments. Mr. Witherell also failed to appreciate that the experiments on pages 131 and 132 which he criticises are not ones upon which the article is based, but that these experiments of Bell were made by Bell to confirm the results of Elbs, and also those of Schwab and Baum; all of these experiments were to determine the effect of iron salts in copper coulometer electrolytes. I merely made reference to these experiments.

The third paragraph under Experimental Part should have convinced the readers that alcohol was not used in the electrolytes of the 36 experiments. The solutions are in a way similar to the pregnant copper solutions obtained in the leaching of copper ores on a large scale. Mr. Witherell and Dr. Fink know that iron salts in the solutions obtained at Chuquicamata cause deleterious effects. I am sorry that Mr. Witherell did not read the article carefully, because had he done so, I feel certain that he would not have made some of the criticisms which he offered. The statement on page 134 ("by operating with a relatively higher current density at the cathode than at the anode, the current is lowered . . . ") is not a typographical error, but is correct.

Commenting on Mr. Witherell's recommendation ("What I recommend he should have done to get valuable figures for copper refiners . . . ") it was not my purpose to obtain figures for the copper refiners, but it was to obtain some data which would be of aid to the copper hydro-electro-metallurgist. I merely presented the results of these experiments, and gave the conclusions, or summary of results, as I saw them. I was in hopes that the paper would be the means of causing some of the practical copper hydro-electro-metallurgists to tell us what they know about the

effect of the presence of iron in the copper solutions when the copper is precipitated by use of insoluble anodes.

Dr. Fink is right when he states that "this problem of the effect of iron on the electrolysis of copper is rather complex." I am glad that there are a number who are busily engaged on experiments along this line, and I hope that when they finish their experiments we will have the opportunity of seeing the results published.

... ...per presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., ... 3, 1918. President Fink in the Chair.

EXPERIMENTS WITH THE COPPER CYANIDE PLATING BATH.[1]

By Frank C. Mathers.[2]

Abstract.

It was found that the current-yields (ampere efficiencies) at the cathodes were generally lower than those at the anodes, hence the necessity of making the regular additions of sodium cyanide to the baths. Sodium carbonate and perhaps sodium sulphate are valuable additions to the bath. In baths containing near to the minimum of sodium cyanide, sodium hydroxide lowered both the anode and the cathode yields. The anode yields are high in both hot and cold solutions if a proper quantity of sodium cyanide is present, but the cathode yields are much lower in the cold solution than in the hot. A bath containing 6 oz. (4.5 percent) copper cyanide, 5.7 to 6.3 oz. (4.3 to 4.7 percent) sodium cyanide and 5.8 oz. (4 percent) sodium carbonate per gallon operated at 160° to 175° F. (60° to 80° C.) is recommended. This is more concentrated than the baths generally used, but it can be operated at a higher current and the deposits are much better.

Introduction.

These experiments were undertaken to study the building up or the increase in copper concentration of the bath. Sodium cyanide must be added regularly to copper baths, otherwise the anodes become covered with slime and do not dissolve. Several things may contribute to the necessity for the addition of the cyanide. It is likely that the sodium cyanide is slowly decomposed in the hot solution into ammonia and sodium carbonate. If the solution builds up or increases in concentration of copper, the addition of cyanide would be necessary to care for this increase. The method of studying the building up was to determine the current yields by comparison with a copper coulometer.

[1] Manuscript received March 26, 1918.
[2] Associate Professor of Chemistry, Indiana University.

Method of the Experiments.

A study was made of the effects upon the current yields by the substances which are ordinarily used in the copper baths. The baths had a volume of 200 c.c. (about 0.5 pint). The cathodes and anodes were each 1.5 in. (3.8 cm.) squares of copper.

Composition of the Bath Used Commercially and Some Results with Cold Solutions.—A bath that is widely employed contains 3.12 oz. (2.34 percent) sodium cyanide, 3 oz. (2.25 percent) copper cyanide, 1 oz. (0.75 percent) sodium carbonate and 0.25 oz. (0.17 percent) sodium hyposulphite. Other formulas give less concentrated baths, but preliminary experiments showed that much better current yields, better deposits and higher current strengths could be obtained with the more concentrated solution, hence all of the following experiments were with baths containing 6 oz. (4.5 percent) of copper cyanide. The hyposulphite is used only as a brightener, hence it was not tried in these experimental baths. At room temperature and 6 amp. per sq. ft. (0.65 amp. per sq. dec.), solutions containing 7.6 oz. (5 percent) or more of sodium cyanide and 6 oz. (4.5 percent) copper cyanide gave anode yields of approximately 100 percent but the cathode yields were from 84 to 89. With smaller amounts of sodium cyanide the anode yields were reduced, but the cathode yields never reached 100 percent. Sodium carbonate did not show much effect, but sodium hydroxide (3.2 oz. or 2.4 percent) distinctly lowered the anode yield. With larger quantities of sodium cyanide, the sodium hydroxide did not show this effect. In several cases, small amounts of Rochelle salt (0.7 oz. or 0.5 percent) increased the cathode yields and kept the anodes bright and more free from a dark color. The results with these cold solutions show that the baths would build up very rapidly due to the quantity of copper dissolved from the anodes being greater than that deposited upon the cathodes.

Hot Solutions.—Baths heated to 175° F. (80° C.) gave high cathode yields and excellent cathode deposits. For these reasons it is inadvisable to work a cold solution. The table on page 133 shows the results of the experiments with the hot solutions. Each bath contained 6 oz. (4.5 percent) copper cyanide. The compositions are given in percentages (grams for 100 c.c.) and may be changed to oz. per gal. by multiplying by 1.33.

Copper Cyanide Plating Baths, With Hot Solutions.

No.	Composition in Percent					Current Yields in Percent					
						6 Amp. per Sq. Ft.		10.8 Amp. per Sq. Ft.		6 Amp. per Sq. Ft.	
	NaCn	Na_2CO_3	NaOH	Rochelle Salt	Na_2SO_4	Anode	Cathode	Anode	Cathode	Anode	Cathode
26	5.4	....	....	....	....	100	97	....	....	....	....
27	5.4	....	0.5	....	....	....	94	....	....	....	....
28	5.4	....	1.0	....	....	100	92	....	....	....	....
29	5.4	....	2.0	....	....	100	90	....	....	....	....
30	5.4	0.5	....	....	....	96	97	....	....	....	....
31	5.4	1.0	....	....	....	100	97	....	....	....	....
32	5.2	....	0.5	....	0.5	100	97	....	....	....	....
33	5.2	....	0.5	....	1.0	101	97	....	....	....	....
36	5.2	....	....	0.5	....	101	94	....	....	....	....
37	5.2	....	....	1.0	....	101	96	....	....	....	....
38	4.7	0.7	....	....	....	....	....	100	*	....	....
39	4.5	....	....	....	....	....	....	100	*	....	....
40	4.7	....	....	....	....	....	....	100	96*	....	....
41	4.9	....	....	....	....	....	....	....	95	....	....
42	4.7	....	1.0	....	....	....	....	78	91	....	....
43	4.7	....	4.0	....	....	....	....	0	72	....	....
44	4.7	4.0	....	....	....	....	....	100	97†	....	....
45	4.7	....	....	....	1.0	....	....	100	98	....	....
46	4.7	....	....	....	4.0	....	....	97	95	....	....
47	4.7	....	....	4.0	....	....	....	98	95	....	....
56	4.1	1.0	....	....	....	....	....	....	....	101	101
57	4.1	1.0	....	....	4.0	....	....	....	....	96	101
58	4.3	1.0	....	....	4.0	....	....	....	....	101	....
59	4.5	1.0	....	....	4.0	....	....	....	....	98	....
60	4.1	4.0	....	....	....	....	....	....	....	100	100
61	4.3	4.0	....	....	....	....	....	....	....	100	100
62	4.5	4.0	....	....	....	....	....	....	....	103	97

* Poor deposits. Loose material on edges. † Excellent deposit.

Effect of Heat.—Baths 26 to 31 averaged 94 percent cathode yields, while they only gave 85 percent in cold solutions. It must be remembered also that these baths contained more sodium cyanide than is required for a hot solution. The most important effect of the heating is to increase the current yield at the cathode.

Effect of Sodium Cyanide.—Baths 38 to 41 show that a variation of free cyanide from 4.5 percent to 4.9 percent makes no difference in the results. With too low a quantity of cyanide the cathode tends to be less smooth and firm.

Effect of Sodium Hydroxide.—Baths 42 and 43 show the injurious effect of free sodium hydroxide. With 4.7 percent sodium cyanide, 1 percent of sodium hydroxide reduced the anode yield to 78 percent and 4 percent of sodium hydroxide brought it to 0. By increasing the cyanide to 5.2 percent in each of these baths, the yields became 96 and 80 for the anodes and 83 and 53 for the cathodes respectively. The injurious action was most noticeable when the bath was operated under severe conditions as regards high current and low cyanide content. These results show that sodium hydroxide should not be added to the baths unless it has some other action than those studied in these experiments.

Effect of Sodium Carbonate.—Baths 44 and 60 to 62, show that sodium carbonate is a valuable addition. With low cyanide (4.1 percent) the anode yield was perhaps no lower than without the sodium carbonate even at very high currents. With more cyanide (4.7 percent), the anode yield was 100 percent and the cathode yield was 97 percent. Moreover the deposits had a better color and were smoother on the edges than without the sodium carbonate. At lower currents, the yields were approximately 100 percent at both electrodes.

Effect of Sodium Sulphate.—Baths 32, 33, 57, 58 and 59 show that sodium sulphate does not lower either the anode or the cathode yield. The color of these deposits was excellent. The use of sodium sulphate seems of advantage, but enough experiments were not tried to prove it.

Effect of Rochelle Salt.—Rochelle salt gave the baths a blue color. It had a tendency to cause loosely attached particles to form upon the edges of the cathodes. In view of the better anode

corrosion which it produced when only small quantities of cyanide were present, a further study of its use should be made.

Conclusions and Recommendations.

1. A more concentrated solution than the one usually employed is recommended. With the more concentrated solution, a higher current can be employed, a thicker deposit can be obtained without bad edges or corners and the cathode yields are higher.

2. The bath should be worked hot on account of the better cathode yields.

3. Very little free cyanide is required to keep the anode corrosions almost to 100 percent in either hot or cold solution.

4. Sodium carbonate is of advantage and it seems that sodium sulphate is likewise a help. The effects of these substances should be studied under conditions of commercial operation for a long period of time before definite conclusions should be drawn concerning them.

6. Under all conditions of operation that give a satisfactory deposit, the anode current yields are likely to be higher than those of the cathode, hence there is a building up or an increase in copper concentration.

6. Sodium cyanide in sufficient quantity to replace that which is lost by decomposition and that neutralized by the extra copper which gradually accumulates, is all that is required to maintain the bath.

7. The following composition is recommended:

	Percent	Oz. per Gal.
Copper Cyanide, CuCn	4.5	6
Sodium Cyanide, NaCn	4.3 to 4.7	5.7 to 6.3
Sodium Carbonate, Na_2CO_3	4.0	5.3

This bath gave approximately 100 percent current yields at both electrodes, hence there would be little increase in metal content. However, there is a tendency for the cathode yields to be lower than those of the anode whenever the operating conditions become severe or when too much cyanide is present.

8. This bath can be operated at 6 to 9 amp. per sq. ft. (0.65 to 1 amp. per sq. dec.) which is double that which can be used on the dilute baths ordinarily recommended. A higher current can be used, but the current yields are lower and the deposits are less smooth.

DISCUSSION.

G. B. HOGABOOM[1]: The author compares a hot solution and a cold solution, and finds that from the hot solution you can get a larger yield of copper than from a cold solution. But he goes to an extreme in recommending a solution so hot as to render it impractical for commercial electroplating processes. In the electrodeposition from copper cyanide solution for ornamental purposes, upon which subject this paper is mostly written, the question of the amount of metal is not so important as the question of the character of the deposit, and while Dr. Mathers says that the character of the deposit is improved, from a very hot solution, I wish to take issue with him. A deposit from a hot solution includes much hydrogen and is very brittle, and if it is run upon work that is to be oxidized in a sulphide solution, or some work that is to be soft soldered, he will find that it is very essential that he should use a colder solution. I saw some experimental work conducted very recently in which some parts were being copper-plated in a hot solution, and they were an absolute failure when we came to solder the two pieces together. Plated in a cold solution the soldering was very successful. It is true that the hot solutions do plate much more rapidly, but there is a limit to the time in which work must be kept in solution. In copper refining, where you put an electrode in and can allow it to stay 14 days or 28 days, it is well and good to say how fast the metal shall be deposited, but in a plating shop where it is required to clean the work previously so that the deposit will be perfectly adherent, it takes some time to do it, and if the metal is deposited too fast, say a thousandth of an inch in about eight minutes, you cannot clean the work fast enough for the plating baths; therefore it would be impractical to run in a factory. You can, from a solution run at 110° F. (43° C.), get a deposit of a thousandth of an inch in fifteen minutes, and that is generally the commercial rate of handling hot solutions.

Another factor is, that in a hot solution the decomposition of cyanide at 180° F. (82° C.) as against 100° F. (37° C.), is five times as great.

[1] U. S. Government Electroplating Expert, Washington, D. C.

Another point is concentration. The author recommends that a solution of about 4.3 to 4.7 percent of copper be used. I am afraid that such a solution would not be applicable to steel works. I am afraid Dr. Mathers would find that if he would apply that in every-day practice upon polished steel, he would have his work very badly blistered. We ran a series of experiments extending over nine months, analyzing the solution twice a day, on 2400 gallons of solution, and found with three ounces of silver per gallon that the results were much more satisfactory and we could get just as good results and the required amount of deposit in fifteen minutes as we could with solution carrying six ounces, with less trouble in blistering, and that the deposit was much more firm.

The only addition agents of which Dr. Mathers speaks are sodium hydroxide and sodium carbonate. He eliminates sodium hydroxide by saying it is useless in a solution, which is true. It is a very fine addition agent in copper, zinc and brass solution, but in copper cyanide solution it is a very poor addition agent. As for sodium carbonate, a new solution when made does not work well if it is made from just sodium cyanide and copper cyanide. It needs something as an addition agent to age it and the best is sodium carbonate. If you make up a new solution of sodium cyanide and copper cyanide, you will get either no deposit or else the deposit is very rough, but by the addition of sodium carbonate, you can get a good deposit; but once it is added, it should never be added again, because the decomposition of cyanide will increase the carbonate content. Inside of a year I have seen solutions which have as high as 14 ounces of sodium carbonate per gallon (1 percent) run at 100° F. (37° C.). I have seen solutions run at 180° F. (82° C.) that have gone up to 24 ounces of sodium carbonate per gallon (1.7 percent) in less than three months, while its density will increase from 11° to 30° Baumé, if sodium cyanide is kept at standard amount. I am speaking of solution worked 10 or 11 hours a day, as we work our solution in an automatic machine.

The paper considers only a small experimental solution in which the anode and the cathode are equal, and it is due to that latter fact that the author gets abnormal results as to the copper building up in the solution. Dr. Mathers recommends 5.3 percent of

sodium carbonate, but I will stake my reputation that he can not run a solution of that formula and get a good deposit, commercially. He will blister polished steel every solitary time.

C. S. WETHERELL[2]: I would like to ask Mr. Hogaboom if it is the practice to add barium cyanide for offsetting the increase of sodium carbonate?

G. B. HOGABOOM: That question brings up a very interesting principle. They do add barium cyanide to reduce the sodium corbonate, but it is a bad practice and a dangerous practice, because you have to add the barium cyanide in small quantities so as not to increase the free cyanide content too greatly. In doing that you get an insoluble precipitate of barium carbonate at the bottom of the solution, and as you pick out your work, picking up a batch every 15 minutes, you stir your solution up and make a rough deposit. I did some work of removing carbonate from a solution by lowering the temperature this winter. I published a paper on that subject a few years ago. This winter we took about 3000 gallons of brass solution, put it in barrels, and carried them out of doors. On some of the cold nights the carbonate crystallized out, and we syphoned off the solution, brought it back and added it to the tank, built it up and only lost one-half percent of metal and started it all over again. I know of 2400 gallons of copper solution, from which they got, by that process, 1600 pounds of sodium carbonate, and we can use it right over again in an old electric cleaner.

F. C. MATHERS (*Communicated*): Mr. Hogaboom overlooks the fact that these experiments were intended to study only building up of the copper concentration of the bath, and were not a study of the things he criticises. On this point he concludes that the abnormal results are due to the small-scale experiments. I do not believe this. His definite quantitative results on this point would have been valuable.

Practical platers could render great service to the science of plating if they would publish more of their observations, such as Mr. Hogaboom has given in his remarks.

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A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

ELECTROLYTIC REFINING OF TIN.[1]

By Edward F. Kern.[2]

Abstract.

A record of experiments to determine the best electrolyte, the best current density and the best addition agent to use in electrorefining impure tin bullion, with the object of saving the precious metals and getting pure tin. Addition agents were found necessary in all cases; aloin and boric acid were good in specific electrolytes, and peptone in all those tried. Stannous fluosilicate solution, containing free hydrofluoric acid with aloin as addition agent, electrolyzed at 24 amperes per square foot (2.7 A. per sq. dm.), gave the best results. [J. W. R.]

The commercial refining of tin by electrolysis is one of the recent industries encouraged by the war, due to the demand for tin of extreme purity. The increased demand for tin has also been the cause of mining South American tin ores which were formerly difficult to dispose of to smelters, as the tin was associated with other base metals which could not be entirely separated from the purified tin, by pyro methods, and also in some cases the impure tin contained silver and gold in such amount to suggest electrolytic refining.

A paper on the "Electro-deposition of Tin" was prepared by the author as a contribution to the Symposium on the Electrodeposition of Metals, in accord with the request of the former President of this Society, and may be found in the "Transactions," 1913, **23**, 193 to 232. A review of the Electrolytic Refining of Tin is given on pages 219 to 232.

[1] Manuscript received April 2, 1918.

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EXPERIMENTAL.

The experiments upon which this article is based were conducted by Mr. Fan Chen in the Electro-metallurgical Laboratory of the School of Mines of Columbia University. The work was undertaken with the idea of finding a suitable tin electrolyte, and the proper working conditions for electrolytically refining tin bullion, so as to obtain the tin as an adherent, dense, compact cathode deposit.

The anodes were crude tin, cast into thin plates 4 inches (10 cm.) long, 1¾ inches (4.4 cm.) wide, and ⅜ inch (0.94 cm.) thick. Analysis gave (in percents) 96.0 tin, 0.5 iron, 0.1 arsenic, 0.2 antimony, 2.0 lead, 0.6 copper, 0.1 bismuth, and 0.5 silver. The cathodes were made of sheet tin 1/64 inch (0.4 mm.) thick, and larger than the anodes by a quarter of an inch (0.6 cm.) on each of the two edges and bottom.

The electrolytes which were selected for trial were solutions of stannous chloride ($SnCl_2$), sodium-stannous chloride ($SnCl_2.2NaCl$), ammonium-stannous chloride ($SnCl_2.2NH_4Cl$), magnesium-stannous chloride ($SnCl_2.MgCl_2$), sodium-stannous fluoride ($SnF_2.2NaF$), stannous fluosilicate ($SnSiF_6$), and a mixture of acid solutions of stannous fluoride and fluosilicate. Each of these solutions was prepared to contain 5 grams of tin per 100 cc., as given below.

Stannous Chloride Electrolyte: A calculated amount of pure stannous chloride was dissolved in a calculated amount of dilute hydrochloric acid, so as to give the solutions 1*a* and 1*b* of Table I. When the tin salt was dissolved, the solution was diluted to a certain volume so as to contain 5 grams of tin per 100 cc. Two electrolytes were prepared, one containing 2.5 grams of anhydrous hydrochloric acid per 100 cc., and the other 7.5 grams of anhydrous hydrochloric acid per 100 cc.

Sodium-stannous Chloride Electrolyte: Calculated amounts of sodium chloride and of stannous chloride were dissolved in a small amount of dilute hydrochloric acid to give a clear solution, and then evaporated to dryness. The dry salts were re-dissolved in water, and just sufficient hydrochloric acid added to give clear

solutions. Three solutions were prepared, as given in Table I: the first (2*a*) contained only the theoretical amount of sodium chloride to form the double salt ($SnCl_2.2NaCl$); the second (2*b*) contained an excess of sodium chloride to give an electrolyte containing 2.5 grams excess NaCl per 100 cc.; and the third (2*c*) contained 7.5 grams excess NaCl per 100 cc.

Ammonium-stannous Chloride Electrolyte: These solutions were prepared in the same manner as the sodium-stannous chloride electrolytes, as described above. Their composition is given in Table I, 3*a*, 3*b*, and 3*c*.

Magnesium-stannous Chloride Electrolytes: These solutions were prepared in the same manner as the sodium-stannous chloride electrolytes. Their composition is given in Table I, 5*a*, 5*b*, and 5*c*.

Sodium-stannous Fluoride Electrolyte: The tin in the form of freshly precipitated stannous hydroxide (prepared by addition of solution of sodium carbonate to slightly acid solution of stannous chloride, filtered and thoroughly washed to remove chloride) was dissolved in a calculated amount of dilute hydrofluoric acid containing the theoretical amount of sodium fluoride so as to produce an electrolyte containing 5 grams of tin as the double salt of sodium-stannous fluoride ($SnF_2.2NaF$), as given in Table I (6).

Stannous Fluosilicate Electrolytes: The tin was precipitated from a slightly acid solution of stannous chloride by means of a solution of sodium carbonate, the precipitate was washed free of chlorides and alkali, first by decantation and then on a filter; the moist precipitate of stannous hydroxide was then dissolved in a calculated amount of hydrofluosilicic acid (H_2SiF_6) so as to produce the two solutions which are given in Table I (4*a* and 4*b*), one containing 2.5 grams of free H_2SiF_6, and the other 7.5 grams of free H_2SiF_6 per 100 cc. The hydrofluosilicic acid was made by digesting finely pulverized quartz in a calculated amount of hydrofluoric acid (48 percent), using a platinum dish as the container. Loss of H_2SiF_6 was prevented by adding a small quantity of cold water when the solution became so warm as to boil off the acid. Too great amount of water must not be added.

The results of the preliminary runs are given in Table I. The electrolysis was conducted at 20° C., with current density at cathode 12 amperes per square foot (1.3 A. per sq. dm.), and distance between anode and cathode 1¾ inches (4.4 cm.).

A comparison of the cathodes of the preliminary runs, with no addition agents present, as given in Table I, showed that the best deposits were formed in sodium-stannous chloride, and in magnesium-stannous chloride electrolytes. The deposits formed in ammonium-stannous chloride electrolytes were not quite so good as those just mentioned, but were better than the deposits formed in stannous chloride, sodium-stannous fluoride, and stannous fluosilicate electrolytes.

Addition Agents: The electrolytes which were selected to be tried with the presence of organic addition agents were: stannous chloride solution containing 5 grams of tin as chloride and 2.5 grams of free hydrochloric acid per 100 cc. (Table II); sodium-stannous chloride solution containing 5 grams of tin as the double salt ($SnCl_2.2NaCl$) and 2.5 grams of sodium chloride in excess per 100 cc. (Table III); ammonium-stannous chloride solution containing 5 grams of tin as the double salt ($SnCl_2.2NH_4Cl$) per 100 cc. (Table IV); and stannous fluosilicate solution containing 5 grams of tin as $SnSiF_6$ and 7.5 grams of free H_2SiF_6 per 100 cc. (Table V). The sodium-stannous fluoride, and magnesium-stannous chloride electrolytes were not tried with addition agents on account of the high voltage required for the electrolysis. The extremely high potential drop in the case of the sodium-stannous fluoride electrolyte was due to the anode containing lead, which forms an insoluble non-conducting coating of lead fluoride on the anode; when no lead is present in the anode the potential drop is about 0.2 volt.

The addition agents which were selected were aloin, gelatine, peptone (from meat), quinoline, oil of cloves, and boric acid. Solutions of each of the organic addition agents were prepared, using water as solvent for the aloin, gelatine and peptone, and alcohol as solvent for the quinoline and the oil of cloves. The boric acid was added as dry powder to the electrolyte. All of

these agents were added to the electrolytes in the amounts recorded in Tables II, III, IV, and V.

SUMMARY OF RESULTS.

The effect of the presence of the addition agents (aloin, gelatine, peptone, quinoline, oil of cloves, and boric acid) in the electrolytes, was to restrain the formation of non-adherent deposits of needles, spangles, and dendrites. The best deposits were formed in stannous fluosilicate electrolyte containing 5 grams of tin as $SnSiF_6$ and 7.5 grams of free H_2SiF_6 per 100 cc., when the addition agents were present; the best deposits were formed when aloin was present in amount corresponding to 1 gram in 500 cc. of the electrolyte.

Aloin was a suitable addition agent only in the case of stannous fluosilicate electrolyte.

The presence of gelatine in amount corresponding to 1 gram in 500 cc. caused the formation of fairly good deposits in all of the electrolytes. It gave more satisfactory deposits from stannous fluosilicate than from the other electrolytes.

Peptone, when present in amount corresponding to 1 gram per 500 cc., caused the formation of more adherent and more densely compact crystalline deposits. The best deposits were formed in the stannous fluosilicate electrolyte (Table V), when 1 gram of peptone was present in 1,000 cc. of the electrolyte. The deposits formed in all of the other electrolytes, when peptone was present, were not so adherent as the deposits from the fluosilicate electrolyte.

Quinoline had a negative effect in all of the electrolytes except stannous fluosilicate, in which case when present as 1 gram per 500 cc. of electrolyte it caused the formation of a dense, compact, adherent, crystalline deposit.

Oil of cloves had a negative effect in all of the electrolytes except stannous fluosilicate, in which, when added in amount of 1 gram per 1,000 cc. electrolyte, it made the deposit more dense and more adherent.

Boric acid did not produce better deposits in any of the electrolytes, except stannous fluosilicate. The presence of 1 gram

of boric acid per 1,000 cc. of stannous fluosilicate electrolyte made the deposit more compact and more adherent; its presence in the other electrolytes caused the tin to deposit as finer needles and as finer dendrites.

USE OF HIGHER CURRENT DENSITY, WITH ADDITION AGENTS.

The electrolyses were repeated by operating with current at 24 amperes per square foot with those solutions and with the addition agents present which gave the most satisfactory deposits, as reported above. The results of these runs at 24 amperes per square foot of cathode surface are summarized as follows:

The deposits which formed with current density 24 amperes per square foot of cathode surface were similar to those which were produced when operating at 12 amperes per square foot, with peptone as the addition agent in sodium-stannous chloride electrolytes containing 2.5 grams excess NaCl per 100 cc. (Table III), stannous chloride electrolyte (Table II), ammonium-stannous chloride electrolyte (Table IV), and stannous fluosilicate electrolyte (Table V). The potential drop at 24 amperes per square foot was 0.24 volt for the sodium-stannous chloride electrolyte, 0.35 volt for the stannous chloride electrolyte, 0.26 volt for the ammonium-stannous chloride electrolyte, and 0.4 volt for the stannous fluosilicate electrolyte.

Aloin, gelatine, quinoline, and oil of cloves, when present in stannous fluosilicate electrolyte (Table V) in amount corresponding to 1 gram per 500 cc., with current density of 24 amperes per square foot of cathode surface, gave deposits similar to those formed when operating with current density of 12 amperes per square foot of cathode surface. The potential drop when aloin was present was 0.32 volt, with gelatine and with quinoline present 0.36 volt, and with oil of cloves 0.4 volt.

When electrolyzing with current density of 24 amperes per square foot, and when boric acid was present, the deposits formed as a mass of spangles and dendrites which soon short-circuited the electrodes. The potential drop was 0.3 volt.

The presence of free hydrofluoric acid (HF) along with the free hydrofluosilicic acid (H_2SiF_6) in stannous fluosilicate elec-

trolyte made deposits more dense and more adherent than when no free hydrofluoric acid was present. The electrolyte which was tested contained 4 grams of hydrofluoric acid and 6 grams of free hydrofluosilicic acid per 100 cc. solution.

The anodes of all the above runs, and also of those at current density of 12 amperes per square foot, were evenly corroded, and the anode residues remained as a thick mud which adhered to the anode.

CONCLUSIONS.

(1) Addition agents are necessary for the electro-deposition of dense adherent deposits of tin.

(2) Stannous fluosilicate electrolyte is the best of the electrolytes tried for the electrolytic refining of crude tin. Free hydrofluoric acid and free hydrofluosilicic acid are beneficial; HF 60 percent of the total acid content is not detrimental.

(3) The deposits of tin which are formed in sodium-stannous chloride, ammonium-stannous chloride, and stannous chloride electrolytes are similar, when addition agents are present.

(4) Aloin was found to cause the formation of the best deposits when added to stannous fluosilicate electrolytes, in amount corresponding to 1 gram per 500 cc. of electrolyte.

(5) Peptone, when added in amount of 1 gram per 500 cc. of electrolyte, gave good deposits from all of the electrolytes reported in Tables II, III, IV, and V.

Gelatine, quinoline and oil of cloves, when present in amounts of 1 gram per 500 cc. of electrolyte, did not improve the deposition of tin, except in the case of the stannous fluosilicate electrolyte.

Boric acid, when added in amounts of 1 gram per 1,500 cc. of electrolyte and up to the saturation point, did not improve the electro-deposition of tin, except when added to stannous fluosilicate electrolyte in amount corresponding to 1 gram per 1,000 cc. of solution.

TABLE I. *No Addition Agents Present.*

C. D. = 12 Amperes per Square Foot. Temp. = 20° C.

No.	Composition of Electrolyte. 5 Grams of Tin + the Following, per 100 cc. Solution	Potential Drop	Character of Electrode Deposit
1*a*	$SnCl_2$ + 2.5 gm. free HCl.....	0.10–0.12	Long, bright, moss-like dendrites, which short-circuited electrodes.
b	$SnCl_2$ + 7.5 gm. free HCl.....	0.10–0.11	Bright, long needles. Poorer deposit than 1*a*. Electrodes short-circuited.
2*a*	$SnCl_2.2NaCl$.....	0.16–0.15	Dense crystalline deposit, with small dendrites along edges of cathode.
b	$SnCl_2.2NaCl$ + 2.5 gm. NaCl..	0.13–0.14	Very dense crystalline deposit; few dendrites along edges of cathode. Good.
c	$SnCl_2.2NaCl$ + 7.5 gm. NaCl..	0.14–0.16	Dense crystalline deposit, with moss-like dendrites along edges.
3*a*	$SnCl_2.2NH_4Cl$.....	0.13–0.16	Dense crystalline deposit with few dendrites along edges of cathode. Fairly good.
b	$SnCl_2.2NH_4Cl$ + 2.5 gm. NH_4Cl	0.11–0.13	Less dense than 3*a*; bright needles scattered over surface. Electrodes short-circuited.
c	$SnCl_2.2NH_4Cl$ + 7.5 gm. NH_4Cl	0.11–0.12	Bright, long needles covered cathode, which soon short-circuited electrodes.
4*a*	$SnSiF_6$. + 2.5 gm. H_2SiF_6.....	0.13–0.16	Dense mass of moss-like dendrites, which soon short-circuited electrodes.
b	$SnSiF_6$. + 7.5 gm. H_2SiF_6.....	0.12–0.14	Dense crystalline deposit, with some needles on edges. Better than 4*a*.
5*a*	$SnCl_2.MgCl_2$.....	0.26–0.28	Dense crystalline deposit, very few needles along edges.
b	$SnCl_2.MgCl_2$ + 2.5 gm. $MgCl_2$.	0.24–0.28	Very dense crystalline deposit. Better than 5*a*.
c	$SnCl_2.MgCl_2$ + 7.5 gm. $MgCl_2$.	0.26–0.28	Very dense crystalline deposit. Similar to 5*b*.
6	$SnF_2.2NaF$.....	0.60–0.70	Surface of cathode covered with dense mass of needles.

TABLE II. *Stannous Chloride Electrolyte Containing 2.5 Percent Free HCl.*

(Similar to 1*a* of Table I.)

C. D. = 12 Amperes per Square Foot. Temp. = 20° C.

No.	Addition Agent Present		Potential Drop	Character of Cathode Deposit
	Name	1 Gram Per		
A *a*	Aloin	1500 c.c. electrolyte...	0.08–0.1	Bright, dense, crystalline deposit, with moss-like dendrites on edges.
b	"	1000 c.c. " ...	0.08–0.1	Similar deposit to A *a*, but mass of crystals less dense.
c	"	500 c.c. " ...	0.08–0.1	Similar deposit to A *a*, but less dense mass than A *b*.
B *a*	Gelatine	1500 c.c. " ...	0.10–0.14	Mass of dense needles, which soon short-circuited electrodes.
b	"	1000 c.c. " ...	0.10–0.14	Similar to B *a*. The presence of gelatine no aid.
c	"	500 c.c. " ...	0.10–0.14	Similar to B *a*. The presence of gelatine no aid.
C *a*	Peptone	1500 c.c. " ...	0.18–0.24	Dense mass of crystals, and few needles on edge. Fairly good.
b	"	1000 c.c. " ...	0.18–0.24	Dense mass of crystals. Better deposit than C *a*.
c	"	500 c.c. " ...	0.18–0.24	Dense, uniform, compact mass of crystals. Better deposit than C *b*.
D *a*	Quinoline...	1500 c.c. " ...	0.16–0.22	Cathode soon covered with mass of fine moss-like dendrites. Poor.
b	" ...	1000 c.c. " ...	0.16–0.22	Cathode soon covered with mass of spangle crystals. Poor.
c	" ...	500 c.c. " ...	0.16–0.22	Similar to D *b*. Quinoline no aid in forming dense deposits.
E	Oil of Cloves	up to 1 gm. in 500 c.c.	0.15–0.22	Similar to D *c*. Oil of cloves no aid.
F *a*	Boric Acid..	1500 c.c. electrolyte...	0.14–0.18	Long bright dendrites covered cathode, which soon short-circuited.
b	" " ..	1000 c.c. " ...	0.14–0.18	Long bright spangles covered cathode, which soon short-circuited.
c	" " ..	500 c.c. " ...	0.14–0.18	Similar to F *b*.
d	" " ..	33 c.c. " ...	0.14–0.18	Similar to F *b* and F *c*. Boric acid no aid.

TABLE III. *Sodium-Stannous Chloride Electrolyte Containing 2.5 Percent NaCl.*

(Similar to 2*b* of Table I.)

C. D. = 12 Amperes per Square Foot. Temp. = 20° C.

No.	Addition Agent Present		Potential Drop	Character of Cathode Deposit
	Name	1 Gram Per		
A *a*	Aloin	1500 c.c. electrolyte...	0.13–0.14	Large number of moss-like dendrites covered cathode. Soon short-circuited.
b	"	1000 c.c. " ...	0.13–0.14	Similar deposit to A *a*, but shorter and more dense.
c	"	500 c.c. " ...	0.13–0.14	Smooth, dense crystalline deposit, and few small needles. Fairly good.
B *a*	Gelatine	1500 c.c. " ...	0.10–0.13	Dense, smooth, crystalline deposit, with few dendrites which short-circuited.
b	"	1000 c.c. " ...	0.10–0.13	Similar to deposit B *a*, but fewer dendrites.
c	"	500 c.c. " ...	0.10–0.13	Similar to deposit B *b*. Fairly good.
C *a*	Peptone	1500 c.c. " ...	0.11–0.14	Smooth, uniform, dense mass of granular crystals. No dendrites. Good.
b	"	1000 c.c. " ...	0.11–0.14	Similar to deposit C *a*. Good, adherent, smooth, crystalline.
c	"	500 c.c. " ...	0.11–0.14	Better deposit than C *b*. No short-circuits after 6 hours' running.
d	"	500 c.c. " ...	0.11–0.14	Added 1 gram Boric acid per 1500 c.c. solution. Similar deposit to C *c*.
D *a*	Quinoline...	1500 c.c. " ...	0.13–0.14	Mass of loosely attached granular crystals, which soon short-circuited.
b	" ...	1000 c.c. " ...	0.13–0.14	Mass of loosely attached spangle crystals, which soon short-circuited.
c	" ...	500 c.c. " ...	0.13–0.14	Poorer than D *a* and D *b*. Mass of hair-like dendrites. Soon short-circuited.
E *a*	Oil of Cloves	1500 c.c. " ...	0.19–0.22	Mass of moss-like dendrites, which soon short-circuited.
b	" " "	1000 c.c. " ...	0.19–0.22	Similar deposit to E *a*.
c	" " "	500 c.c. " ...	0.19–0.22	Similar deposit to E *b*.
F	Boric Acid..	up to saturation.....	0.17–0.22	Presence of boric acid caused poorer and less adherent deposits.

TABLE IV. *Ammonium-Stannous Chloride Electrolyte.*

(Neutral Solution Similar to 3*a* of Table I.)

C. D. = 12 Amperes per Square Foot. Temp. = 20° C.

No.	Addition Agent Present		Potential Drop	Character of Cathode Deposit
	Name	1 Gram Per		
A *a*	Aloin	1500 c.c. electrolyte...	0.14–0.16	Mass of dense needles and blades, which soon short-circuited electrodes.
b	"	1000 c.c. " ...	0.14–0.16	Mass of dense needles and blades, which soon short-circuited electrodes.
c	"	500 c.c. " ...	0.14–0.16	Mass of dense needles and blades, which soon short-circuited electrodes.
B *a*	Gelatine	1500 c.c. " ...	0.14–0.18	Mass of short crystals and dendrites, soon short-circuited electrodes.
b	"	1000 c.c. " ...	0.14–0.18	Slightly better deposit than B *a*, crystals shorter and less dendrites.
c	"	500 c.c. " ...	0.14–0.18	Mass of coarse crystals, and few dendrites on edges of cathode.
C *a*	Peptone	1500 c.c. " ...	0.14–0.16	Compact, uniform mass of granular crystals. No dendrites. Fairly good.
b	"	1000 c.c. " ...	0.14–0.16	Better deposit than C *a*, more compact and smoother.
c	"	500 c.c. " ...	0.14–0.16	Better deposit than C *b*, compact and smooth coating of fine crystals.
D *a*	Quinoline...	1500 c.c. " ...	0.14–0.16	Non-adherent mass of long needles and spangles, which soon short-circuited.
b	" ...	1000 c.c. " ...	0.14–0.16	Mass of bright, dense crystals, and few dendrites on edge.
c	" ...	500 c.c. " ...	0.14–0.16	Slightly better, and similar to deposit D *b*.
E *a*	Oil of Cloves	1500 c.c. " ...	0.16–0.18	Non-adherent mass of needles and spangles, which soon short-circuited.
b	" " "	1000 c.c. " ...	0.16–0.18	Similar to deposit E *a*.
c	" " "	500 c.c. " ...	0.16–0.18	Slightly better than deposit E *b*.
F	Boric Acid..	up to saturation.....	0.14–0.16	Presence of boric acid no apparent effect.

TABLE V. *Stannous Fluosilicate Electrolyte Containing 7.5 Percent* H_2SiF_6.

(Similar to 4*b* of Table I.)

C. D. = 12 Amperes per Square Foot. Temp. = 20° C.

No.	Addition Agent Present		Potential Drop	Character of Cathode Deposit
	Name	1 Gram Per		
A *a*	Aloin	1500 c.c. electrolyte...	0.14–0.15	Dense mass of bright slender, small needles.
b	"	1000 c.c. " ...	0.14–0.15	Slightly better deposit than A *a*.
c	"	500 c.c. " ...	0.14–0.15	Very good deposit, which was bright, compact, dense and adherent.
B *a*	Gelatine	1500 c.c. " ...	0.14–0.16	Very dense, compact, even crystalline and adherent. Few dendrites on edge.
b	"	1000 c.c. " ...	0.14–0.16	Better deposit than B *a*. Few dense nodules on edge. Good.
c	"	500 c.c. " ...	0.14–0.16	Similar to B *b*. Good, dense, smooth, crystalline adherent deposit.
C *a*	Peptone	1500 c.c. " ...	0.16–0.18	Very bright, compact, smooth and dense deposit, few nodules on edge. Good.
b	"	1000 c.c. " ...	0.16–0.18	Slightly better deposit than C *a*, fewer nodules on edge. Good.
c	"	500 c.c. " ...	0.16–0.18	Similar to deposit C *b*. Good.
D *a*	Quinoline...	1500 c.c. " ...	0.18–0.21	Uniform dense crystalline deposit. Few hair-like dendrites on edge.
b	" ...	1000 c.c. " ...	0.18–0.21	Slightly better deposit than D *a*, fewer dendrites on edges.
c	" ...	500 c.c. " ...	0.18–0.21	Slightly better deposit than D *b*, fewer dendrites on edges.
E *a*	Oil of Cloves	1500 c.c. " ...	0.19–0.20	Bright, smooth, compact crystalline deposit, few small nodules on edge.
b	" " "	1000 c.c. " ...	0.19–0.20	Good deposit, similar to E *a*, but fewer nodules on edges.
c	" " "	500 c.c. " ...	0.19–0.20	Good deposit, similar to E *b*.
F *a*	Boric Acid..	1500 c.c. " ...	0.14–0.16	Needles and dendrites covered cathode, which soon short-circuited.
b	" " ..	1000 c.c. " ...	0.14–0.16	Fairly compact uniform mass of crystals, few nodules on edges. Fairly good.
c	" " ..	500 c.c. " ...	0.14–0.16	Similar to deposit F *b*. Fairly good.
d	" " ..	saturated " ...	0.14–0.16	Non-adherent deposit of fine needles and dendrites. Very poor.

Electro-metallurgical Laboratory,
School of Mines of Columbia University, March, 1918.

DISCUSSION.

C. S. WITHERELL[1]: Dr. Kern has tackled what is his "long suit" in this paper, particularly when it comes to addition agents. I think he has done about as much work as any one along those lines and given us a great deal of valuable information. He gives you a list of tin electrolytes and their effects, etc., and the nature of the deposits as he found them in the laboratory. In his conclusions he recommends the electrolyte which is now being used in what I believe is the principal electrolytic tin refinery in the United States, that is the fluo-silicate of tin; and he further recommends the use of gelatin as an addition agent, which I believe is also being done at the plant I refer to.

This matter of addition agents is very interesting as well as important. However, I wish to sound a note of caution. Many addition agents when first added give excellent results and may continue to give good results for several weeks, but frequently after two or three months deleterious effects appear. Trouble comes particularly with organic addition agents; they usually undergo a chemical change and the products of decomposition rarely produce beneficial results. On the contrary, they are usually very deleterious, and then you are forced to give up the addition agent which at first appeared good. This, as a rule, is very difficult to discover in the laboratory. Probably one of the reasons you cannot discover it in the laboratory is that large masses of solution behave differently. One of the causes of this undoubtedly is the short circuits that occur. From five to ten percent of the loss of efficiency below 100 can be ascribed to short circuits, either electrodes set out of line—you know in practice they use very large electrodes and it is difficult to get them absolutely plumb—or from growths which connect the cathodes and the anodes. The effect around these short circuits is entirely different from the effects caused by currents passing through the electrolyte in the normal way. There are many other reasons. However, as a caution before you tie up to any addition agent, first try it out in a small part of the works for a long period of time. In a copper refinery using say about 16 to 18 amperes to

[1] Metallurgical Engineer, Chile Exploration Co., New York City.

the square foot (175 to 200 A. per sq. m.), there are about 500 cubic feet (14 cub. meters) of solution per ton day of capacity; therefore with a 200 ton plant, you would have upwards to 100,000 cubic feet (3,000 cub. meters) of solution to correct if spoiled, and it would take considerable time to correct that volume after you had gotten into trouble. So try out your addition agents in a practical way first before tying up to them.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918. President Fink in the Chair.

BRITTLENESS PRODUCED IN STEEL SPRINGS BY ELECTROPLATING.

By O. P. Watts[1] and C. T. Fleckenstein.[2]

Abstract.

Tests on watch springs, to determine whether the brittleness induced in steel by use as cathode in strong cyanide electrolyte is due to the presence of free cyanide or to electrolytically generated hydrogen. The conclusion of the tests is that the latter is the cause of the brittleness.

Under the same caption as the above, M. DeK. Thompson and C. N. Richardson[3] published the results of an experimental investigation of the cause of brittleness in steel springs when plated with copper from a cyanide solution, and concluded that the brittleness observed is due to the cyanide, and not to hydrogen. "These experiments indicate that the cyanide radical in combination with electrolysis is the cause of the brittleness." Another conclusion is, "Brittleness was not produced by the liberation of hydrogen on steel."

The brittleness caused in thin steel springs by pickling in acids for the purpose of removing scale has long been recognized, and has very generally been ascribed to absorption of hydrogen by the steel. That the matter is of interest to technical men is indicated by the fact that two of the papers presented at the last meeting of this society dealt with methods of preventing such embrittling of steel. Coulson[4] removes scale from steel without exposing it to the action of hydrogen by using it as anode, and reports entire freedom from brittleness; Fuller[5] secures the same result when copper-plating steel from a cyanide solution by first

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[2] Student, University of Wisconsin.
[3] Met. & Chem. Eng., 1917, **16**, 83.
[4] Tr. Amer. Electrochem. S., 1917, **32**, 237.
[5] Tr. Amer. Electrochem. S., 1917, **32**, 247.

coating the steel with tin. Although the experiments of Coulson and Fuller indicate that hydrogen is probably responsible for brittleness, they do not absolutely prove this. To secure more definite evidence in the case "Cyanide *vs.* Hydrogen," the authors have carried out a number of experiments, which are here presented.

Watch springs were selected as the material for the tests, since, on account of their thinness and temper, they are particularly susceptible to brittleness. The test for brittleness consisted in bending the spring around a steel rod ¼ inch (6 mm.) in diameter. The untreated springs withstood this test, whether bent with or opposite to their natural curvature. Springs recorded as brittle broke when bent in the same direction as their curvature, by no means a severe test. The springs varied from 0.16 to 0.23 mm. in thickness.

TESTS.

A spring was immersed in 30 percent sulphuric acid for two minutes, and was very brittle after this treatment.

Springs were then used as cathode in several electrolytes from which hydrogen is deposited on the cathode on electrolysis, with the results shown in Table I.

TABLE I.

Exp.	Electrolyte	Time	Amp.	Amp./ sq. dm.	Result
1.	30% H_2SO_4.....	5 min.	0.05	2.5	Spring very brittle.
2.	n.K_2SO_4	5 min.	0.05	2.5	Brittle.
3.	n.HCl	3 min.	0.06	3	Very brittle.
4.	n.KCl	3 min.	0.06	3	Brittle, but less so than No. 3.
5.	NaOH (15.5 g./100 c.c.)	5 min.	0.04	0.26	Not brittle.
6.	NaOH (ditto).....	15 min.	0.04	0.26	Brittle, bluing removed.

When used as cathode in the hot "electric cleaner" at 9 volts and thus exposed to a storm of hydrogen, a spring is rendered quite brittle in 15 seconds, and in 30 seconds is ruined.

In order that electro-plating may adhere to the springs it is necessary that the bluing be removed and that they be freed from every trace of grease. Since the usual means employed for these purposes cause the liberation of hydrogen and render the springs brittle, resort was had to a hot alkaline solution for the removal

TABLE II.

No.	Metal Deposited	Bath	Hydrogen Evolution	Deposit	Brittleness	Time, Min.	Amp.	Amp./sq.dm.
7.	Cu	Cyanide, free Cy.	Yes	Fair	Brittle	20	0.002	0.21
8.	Cu	Alk. tartrate	No	Poor	Not brittle	60	0.002	0.16
9.	Cd	Cyanide	No	Good	Not brittle	39	0.05	2.6
10.	Cd	Cyanide and free Cy.	Yes	Fair	Brittle	40	0.02	0.18
11.	Cd	Fluoborate, acid	Yes	Good	Brittle	30	0.05	0.31
12.	Cd	Fluoborate, faintly acid	No	Good	Brittle	10	0.10	4.2
13.	Au	Cyanide, free Cy.	No	Good	Not brittle	12	0.12	1.1
14.	Zn	Sulphate + Cl	No	Poor	Not brittle	40	0.004	0.46
15.	Zn	Sulphate + Cl, slight acid	No	Poor	Not brittle	40	0.004	0.74
		From Hot Baths, temperatures 82 to 85°C.						
16.	Ag	Cyanide, free Cy.	No	Good	Not brittle	5	0.082	2.0
17.	Cu	Cyanide	No	Poor	Not brittle	7	0.11	0.54
18.	Cu	Cyanide, free Cy.	No	Bright	Not brittle	4	0.11	1.0
19.	Cu	Cyanide, much free Cy.	Yes	Bright	Brittle	5	0.11	0.5

of grease, while the bluing was removed in several different ways: (1) a solution of $FeCl_3$, (2) a boiling solution of 10 grams ammonium citrate in 100 c.c. of water, (3) concentrated hydrochloric acid containing about 3 percent by volume of formalin. The second of these solutions proved most satisfactory, usually removing the bluing in a few seconds without even diminishing the luster of the spring. The third solution acts almost instantaneously, and if the spring is not exposed to its action for more than one second it is not injured, but is rendered brittle by immersion for a minute.

After being freed from grease and bluing, the springs were plated as indicated in Table II. Unless free cyanide is specified, the excess of this usually present in plating baths was removed by adding a salt of the metal to be deposited, until a permanent precipitate resulted. Electrolysis was at room temperature, about 23° C., unless otherwise stated. Since Thompson and Richardson used their cyanide copper bath hot, it was thought desirable to test the effect of heat with a few of these solutions, although it was expected, from the lessened brittleness of iron and nickel when deposited from hot solutions that the only effect of heating the electrolyte would be to lessen somewhat the brittleness of the springs.

In every case in which the evolution of hydrogen could be detected, and in one case where none was observed, the spring was rendered brittle. By removing the free cyanide from the copper solution and using it hot it was possible to deposit copper on the spring without making it brittle, but the plating was too poor to be of value commercially. No. 18, however, was an excellent deposit. Hydrogen is not evolved from silver or gold baths at reasonable current densities even in the presence of free cyanide[6], and in no case did the plating of springs from these solutions render them brittle.

It seems certain that any brittleness of steel springs acquired during plating cannot be due to cyanide, and it seems highly probable that brittleness caused either in pickling or plating is due to hydrogen.

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[6] Tr. Amer. Electrochem. Soc., 1917, 31, 303.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

WHY BUSY RAILS DO NOT RUST.[1]

By Oliver P. Watts.[2]

Abstract.

The author reviews at length the observations made since 1843 on the fact that idle rails appear to rust faster than busy ones. He criticizes some of the attempted explanations, and shows by experiment that they are not valid. Believing galvanic action to be chiefly responsible for the protection of the busy rails, measurements were made which showed the used head of a busy rail to be electrically positive to the rest of the rail. Confirmatory tests were made by straining (cold working) iron rods, showing the worked part to be electro-positive to the unworked. The author concludes that his observations, experiments and explanations have fully exposed the reasons for the phenomenon in question.—[J. W. R.]

It is a common observation that rails in the main line of a railroad never rust seriously, although those made of the same material but laid in a siding where there is little or no traffic, are soon badly rusted.

The observation of this phenomenon dates back to the infancy of the railroad. Robert Mallet[3] quotes a report of George Stephenson as follows: "One phenomenon in the difference of the tendency to rust between wrought iron laid down as rails, and subjected to continual motion by the passage of the carriages over them, and bars of the same material either standing upright, or laid down without being used at all, is very extraordinary. A railway bar of wrought iron laid carelessly upon the ground

[1] Manuscript received March 4, 1918.

[2] Associate Professor of Chemical Engineering, University of Wisconsin.

[3] Report of Brit. Assoc. for the Advancement of Science, 1843, p. 28.

alongside of one in the railway in use, shows the effect of rusting in a very distinct manner; the former will be continually throwing off scales of oxidated iron, while the latter is scarcely at all affected."

In commenting on this observation of Stephenson, Mallet says, "When rails lying parallel on the same line of way, but one set in and the other out of use, are examined, appearances do undoubtedly seem to support the opinion. The unused rails are found covered with red rust, often coming off in scales parallel to the surface, while those in use present a light brown or buffish coat of rust, without any loose scales. I am much disposed however to believe that there is no real difference in the amount of corrosion in the two cases, and that the difference in appearance arises partly from a *deceptio visus,* by the effect of the bright and polished upper face of the used rail (kept so by constant traffic) contrasted with the rusty face of the unused rail, and partly from the fact, that as fast as rust is formed upon the rail in use, it is shaken off by the vibration of passing trains and blown away by the draft of wind which accompanies their motion, and that the rail is soiled and partially blackened by coke and other dust, etc."

From 1842 to 1849 Mallet[4] conducted three series of experiments with full-sized rails, each series comprising rails laid in the track, others laid beside those in use but not traveled over, and still others laid in the track but protected from atmospheric oxidation by a coating of tar. After making allowance for losses by abrasion, he reported the loss by corrosion in grains avoirdupois per square foot per year to be as follows:

Time in Days.	1st Exp. 303	2d Exp. 730	3d Exp. 1460
Rail idle	213.38	76.00	96.18
Rail in use	103.04	32.87	83.53
Difference	110.34	33.13	12.65

Mallet assumed that the top of traveled rails did not corrode, and hence omitted the area of the top in reckoning the surface of used rails. A recalculation of his results on the basis of the total surface of used rails gives 87.30, 27.85, and 70.77 for the losses of rails in use instead of the values published by Mallet; the corresponding differences in corrosion of idle and busy rails

[4] Report Brit. Assoc. for Advancement of Science, 1849, 88.

are 126.08, 48.15, and 25.41 grains per square foot per year. It is noteworthy that the longer the period of exposure, the less the difference between the corrosion of busy and idle rails. This will be referred to again later. In explanation of the different rates of corrosion Mallet calls attention to the fact that "every metal is electropositive to its own oxide," and says, "Now the rust formed upon a railway bar in use is perpetually shaken off by the vibration of traffic, and thus this source of increased chemical action is removed."

W. H. Barlow[5] in 1868 comments on the phenomenon as follows: "The great difference between the effects upon rails laid in a siding and rails laid in the main line was, that the one by the wear of traffic had a polished surface, and the other had not; and he thought it quite possible that a galvanic action arose between the polished and the unpolished surfaces, which tended to preserve the general body of the rail."

Cushman, Friend, and Sang, in their books on the corrosion of iron[6] call attention to this comparative freedom from rust of busy rails, and suggest various explanations for it. Sang says, "Galvanic action between the smooth head of the rail and the rest of it has been suggested to explain this immunity from rust, but it is not at all likely that the foot would owe its protection to the thin stratum of denser metal so far removed from it. If that dense skin on the top of the rail were not crushed beyond its elastic limit, it would, on the contrary, tend to accelerate the corrosion of the steel in contact with it. The real reason for this difference of behavior seems to lie in the observed fact that oxidation is apparently arrested, or at least greatly retarded, by vibration. Explanations seem to stop at this point, but a simple theory can be built on the assumption that the vibration causes a shedding of the rust as soon as it is formed on the spots that are not protected by mill scale, and there is, therefore, no acceleration of the action due to the accumulation of spongy and electro-negative rust."

Commenting on the above explanation, Friend says, "No doubt this is a partial explanation, but the freedom from rapid rusting

[5] Proc. Inst. Civil Eng., 27, 570.

[6] Cushman: Corrosion and Preservation of Iron and Steel, 1910, p. 108.
Friend: Corrosion of Iron and Steel, 1911, pp. 99, 118, 247.
Sang: Corrosion of Iron and Steel, 1910, p. 71.

may be due in part to the rise in temperature caused by the rush of trains over the metals, whereby the rails are maintained at a temperature slightly above that of their surroundings. The result is that liquid water has no good opportunity of condensing upon them, or, if once condensed, it is rapidly vaporized and corrosion retarded."

Cushman ascribes protection to "the fact that frequent and recurring vibration was sufficient to break up points of specific potential differences on the surface."

The idea that rails in constant use owe their immunity to rust to galvanic action between the strained and unstrained metal does not at present seem to be accepted. This is perhaps not strange, for until comparatively recently[7] it had not been surely demonstrated by experiment that cold-working renders iron electropositive, and it was also generally held that the E.M.F. between strained and unstrained iron or steel, granting that a difference of potential exists, is too small to exert a protective effect on the rest of the rail, especially on those parts which are several inches distant from the head of the rail.

Believing galvanic action to be chiefly responsible for the observed difference between the rusting of used and idle rails, the writer endeavored to ascertain if the head of a used rail is really positive to the remainder of the rail, a point which seems to have been left undetermined so far in the discussion of this question. Through the kindness of Mr. G. N. Prentiss, chemist for the Chicago, Milwaukee & St. Paul R. R., a section of used rail was secured. Pieces were cut from the top and the bottom, and covered with paraffine except for one side, so that the exposed surfaces should be approximately equal and that on the piece from the top only the worn surface of the rail should make contact with the electrolyte. The E.M.F. between these pieces was measured in normal potassium chloride by means of a potentiometer. The initial voltage was 0.078 volt, rising in five minutes to a maximum of 0.084, from which value it slowly fell to 0.029 at the end of an hour, during which time the electrodes were not moved. On shaking both electrodes the E.M.F. rose to 0.056, but dropped in 3 minutes to 0.037. The potential measured by a millivoltmeter of 16 ohms resistance immediately after the last reading

[7] Burgess and Thickens: Tr. Amer. Electrochem. Soc., 1908, **13**, 31.

by the potentiometer was only 0.015, which fell in 2 seconds to 0.005 volt. A millivoltmeter is unsuited for reading the E.M.F. between electrodes of such small surface as these, *viz.*, 6 sq. cm.

Instead of removing any slight differences of potential that naturally exist on the surface of the rail, as was contended by one of the authorities on corrosion previously referred to, the passage of trains develops a difference of potential exceeding 80 millivolts, between the upper surface and the rest of the rail. The question now is: To what extent is this E.M.F. responsible for the lessened corrosion of busy rails?

The prevention of the corrosion of iron by connecting the metal as cathode and sending current to it from a source of E.M.F. outside of the corroding solution has been the subject of several investigations, and this principle is the basis of a number of patented processes for preventing the deterioration of metals and alloys when exposed to severe corrosive conditions. Gee[8] found 0.088 ampere per square foot (1 per sq. meter) to be more than sufficient to protect iron from corrosion in 1 percent sodium chloride solution. Harker and McNamara[9] found 0.004 ampere per square foot (0.044 per sq. m.) to be sufficient to prevent the corrosion of iron in sea water, and Clement and Walker[10] obtained the same result by using a current density of 0.11 ampere per square foot in N/100 sulphuric acid. In the Cumberland process for preventing the corrosion of boilers 0.001 ampere per square foot (0.011 per sq. m.) has proved sufficient for the purpose.[8]

That the E.M.F. between strained and unstrained iron is great enough to cause selective corrosion in dilute acids was conclusively proved by the experiments of Burgess and Thickens previously referred to. In view of the small current density that was found to prevent corrosion of iron under the severe conditions of immersion in sea water, it is to be expected that the strained condition of the upper surface of used rails will exert a considerable protective action on the rest of the rail when the electrolyte is so slightly corrosive as is the dew or rain water which wets the rails. It might seem, therefore, that the whole matter has been cleared up; but while the formation of a local couple by contact of two dissimilar metals in an electrolyte lessens the corrosion of the

[8] Trans. Faraday Soc., 1913, **9**, 120.
[9] J. Soc. Chem. Ind., 1910, **29**, 1286.
[10] Trans. Amer. Electrochem. Soc., 1912, **22**, 193.

cathode, the rate of corrosion of the anode is thereby increased, and the question arises whether or not the total loss in weight of both materials is increased or diminished by putting them in contact.

To determine this a bar of mild steel (about 0.4 percent C) ¾ in. (1.9 cm.) square and 4 inches (10 cm.) long, was machined in a lathe to a diameter of ⅝ in. (1.6 cm.) for a distance of an inch (2.5 cm.) in the middle of the bar, leaving the ends unchanged. The bar was then twisted through 180° in a testing machine, by which a local couple having an E.M.F. of 80 millivolts was formed between the cold-worked middle and the unstrained ends. The bar was then machined to a diameter of 0.563 in. (1.4 cm.) throughout its entire length. A similar cylinder was prepared from unstrained metal, and the two were immersed to a depth of 3¼ inches (8.2 cm.) in N/5 hydrochloric acid for 72 hours. After cleaning, drying, and weighing, it was found that the bar in which the local couple had been formed by cold-working had lost 6.768 grams, while the other had lost only 5.436 grams. This means that the efficiency of cathodic protection by the current generated by the local couple was much less than 100 percent; at an efficiency of 100 percent the excessive corrosion of the anodic portion of the bar caused by the voltaic action would have been exactly counterbalanced by the protective effect on the cathodic portions, and the loss in weight of this specimen would have been the same as that of the unstrained metal.

In acid of the same strength as that used in this experiment, and also in sea water, Harker and McNamara found that the corrosion of zinc or iron which naturally occurred in these solutions could be overcome by inserting an anode of the same metal and making the corroding metal cathode, while passing a current exactly equivalent to the amount of metal previously lost. Clement and Walker reported the same condition to hold with regard to the protection of iron in N/100 sulphuric acid even when an insoluble anode was employed, *i. e.*, the efficiency of cathodic protection is 100 percent when the source of E.M.F. which produces the current is situated outside of the corroding solution. The low efficiency of protection found by the writer in the case of strained *versus* unstrained iron, corresponds to the wasting of an unamalgamated zinc in a voltaic cell with an acid electrolyte. In neutral

electrolytes, as when rails are laid in a track, a high efficiency of protection is to be expected, just as there is a high efficiency of utilization of an unamalgamated zinc anode in neutral electrolytes.

Mallet's experiments on the rusting of used and idle rails showed an apparent efficiency for the protective action greatly in excess of 100 percent. It is of course impossible that this can be directly due to the protective effect of current flowing from the head of the rail, but it is a simple matter to find a logical explanation for it. As has already been indicated, it is generally recognized that the presence of rust is a stimulator to further rusting, and that the thickness, age, and porosity of the rust are factors of importance in determining the rate at which rusting proceeds. Traffic keeps bright the upper surface of the rail, where the coat of rust would otherwise be heaviest, and the current flowing from this lessens the thickness, and probably modifies the quality of the coat of rust on other parts of the rail; the result must be a slower accumulation of rust on used than on idle rails (meaning those which have never been used), and therefore less vigorous action by that stimulator of rusting, rust itself. This view is supported by Mallet's observation that the rates of rusting of used and of idle rails become more nearly equal as the time of exposure is increased.

Among explanations offered by previous writers for the lessened corrosion of rails in use are:

1. That vibration causes shedding of rust and so, in the presence of less of this stimulator of corrosion, rusting will be diminished.

2. That vibration breaks up areas of different potential that are naturally present on the surface of iron or steel.

3. That there is a voltaic action between bright or polished and dull or rough iron which, in some manner not explained, lessens the total corrosion of the rail.

4. That the rise in temperature produced by the passing of trains causes a more rapid evaporation of moisture from the used rails, and for this reason lessens corrosion.

This paper proves that an E.M.F. exists between the top and other portions of used rails acting in such a direction as to protect the rest of the rail; but it is manifestly impossible that a current generated by corrosion of one part of a bar of metal in a single

solution shall, by its protective action on the other part, directly lessen the total corrosion.

The writer presents the view that the lessened corrosion of rails in use is due to a combination of two of the causes mentioned by previous writers, *viz.*, voltaic action between strained and unstrained metal in the rail, which results in a slower formation of rust on the cathodic portions, and that thereby the normal accelerative action of rust is greatly diminished; and the complete removal of rust from the top of the rail, where it would otherwise form most rapidly and exert the greatest accelerative effect on rusting.

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DISCUSSION.

C. G. FINK[1]: This subject of corrosion is probably the most important subject of electrochemistry from our Government's point of view, and the Bureau of Standards and other large laboratories have carried out a very large amount of work along this line.

Jos. W. RICHARDS[2]: The phenomenon of the strained part being electro-positive toward the unstrained is due to the fact that work has been done upon it and has changed its shape, and therefore it has a little more energy to give out when it dissolves than if it were unstrained. It is the old question of taking a spring and coiling it; when it is coiled you have stored up in it some mechanical energy. If now that coiled spring is dissolved in acid, it must give out and will give out, in the form of heat, the heat of solution of the unstrained steel plus the equivalent of the mechanical energy which was put into it in cooling it. In the same way, the strained portion has some mechanical energy to give out which the unstrained portion has not, and therefore if you put in a solution a piece of strained iron and a piece of unstrained iron, the strained iron will act as the anode, because in going into solution it gives out more energy than the unstrained.

[1] Head of Laboratories, Chile Exploration Co., New York City.
[2] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.

The strained part of the rail will therefore act as an anode and the unstrained part, which is the rest of the rail, as cathode, and therefore protected by any current which may flow through the film of moisture on the rail.

CARL HERING[3]: Is it an experimental fact that the strained portion is always the anode?

Jos. W. RICHARDS: According to this paper, yes.

CARL HERING: Is there no other evidence?

Jos. W. RICHARDS: I believe that has been rather elaborately tested and proved, and this paper confirms that view.

CARL HERING: I did not question it, and theoretically it seems that it should be so; I was merely interested in knowing whether the fact was established.

H. D. HIBBARD[4]: To the explanation given in the paper should, I think, be added the one that busy rails are being continually spattered with oil. The explanations given in the books of the last century seemed to me inadequate, and for the past forty years I have considered the protecting influence of oil to be the reason why busy rails rusted less rapidly than those in an idle track alongside. I have thought that idle rails between busy rails such as guard rails at bridges and at frogs rusted no more rapidly than the rails which bore the traffic, but know of no determinations bearing on that point, though it may be worthy of quantitative study.

A drop of oil on a warm rail, as in summer time, spreads to many times its original area and its protective power is quite lasting.

O. P. WATTS (*Communicated*): Mr. Hering will find further experimental evidence, corroborated by photographs, of the fact that strained iron is anodic to the unstrained metal, in reference 7 of this paper, the presidential address delivered by C. F. Burgess before this Society in 1908.

[3] Consulting Electrical Engineer, Philadelphia, Pa.
[4] Consulting Metallurgist and Engineer, Plainfield, N. J.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918. President Fink in the Chair.

THERMO-ELECTROMOTIVE FORCE OF SOME ALLOYS.[1]

By M. A. Hunter and J. W. Bacon.[2]

Abstract.

The authors had previously studied and reported on the electrical resistivities of some binary and ternary alloys of iron, nickel and copper, with chromium and manganese. They now study the thermo-electromotive forces of these alloys, at different temperatures up to 900° C. Some very useful alloys for thermo-couples were found.—[J. W. R.]

In two previous papers[3] we have communicated the results of experiments on the electrical resistivities and temperature coefficients of some binary and ternary alloys of iron, nickel and copper with chromium and manganese.

The present paper deals with the thermo-electromotive forces of these combinations.

The measurements were obtained by joining a number of the wires directly to a standard iron-constantan thermo-couple, with soft Swedish iron wire. The standard thermo-couple indicated the temperature of the hot junction. The thermo-electromotive force of each individual wire was then taken against the iron of the standard thermo-couple. The cold junction was maintained at room temperature (20° C.). In determining the temperature of the electric furnace used a correction was made for the cold junction temperature of the standard thermo-couple.

This standard thermo-couple with its calibration was supplied by the Leeds & Northrup Co. The standard iron of this thermo-

[1] Manuscript received March 5, 1918.

[2] Rensselaer Polytechnic Institute, Troy, N. Y.

[3] Trans. Am. Electrochem., 1916, **29**, 569-578.
Trans. Am. Inst. of Metals, 1917, **11** (2), 115-138.

couple is a soft iron of low carbon content. The effect of carbon on the thermo-electric power of iron has been already indicated by Belloc.[4] The variations in the E. M. F. of several grades of

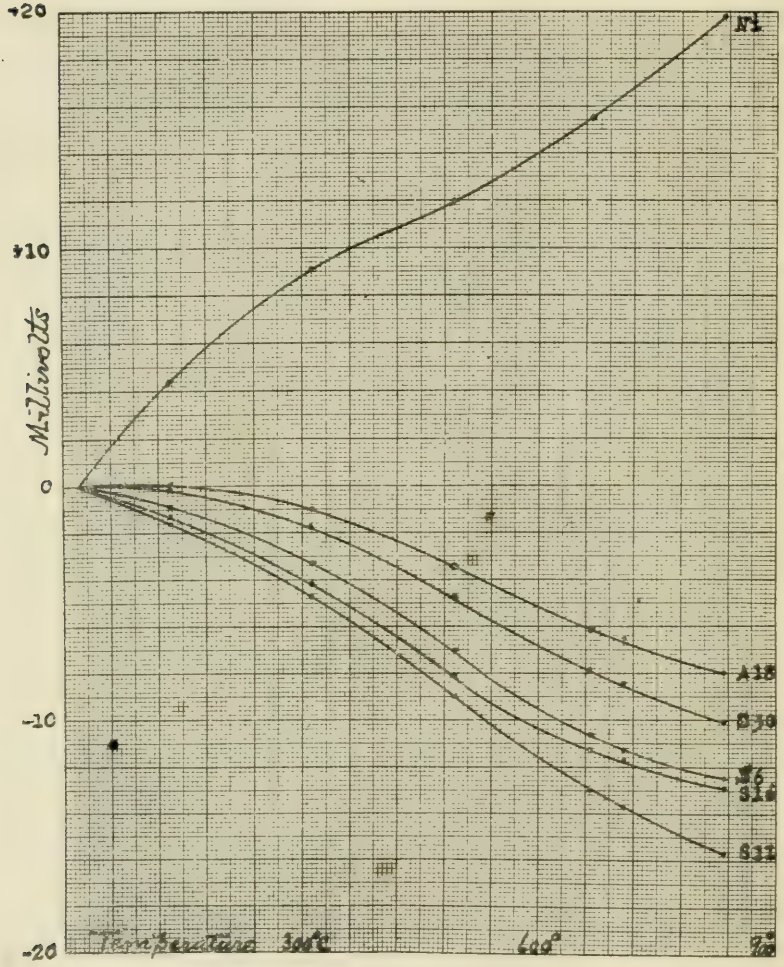

PLATE I. Nickel-Chromium Alloys.

iron of varying carbon content are shown to be of the order of a few microvolts, in the various specimens. In a private communication from Mr. F. E. Bash, of the Leeds & Northrup Co.,

[4] Belloc: Ann. de Chim. et de Phys. (6), **30**, 42 (1903).

the effect of varying carbon content on the E. M. F. of iron against a piece of standard constantan at 1,500° F. (815° C.) is shown in the following table:

	Carbon Content, Percent	Variation from Standard
Cold rolled steel	0.12	+4° F. (+2.2° C.)
Iron—Coil No. 2	0.12	—3° F. (—1.7° C.)
Soft iron	0.05	±0° F. (±0° C.)
Iron—Couple No. 124	0.20	—20° F. (—11° C.)
Stubb's steel	1.25	—41° F. (—24° C.)

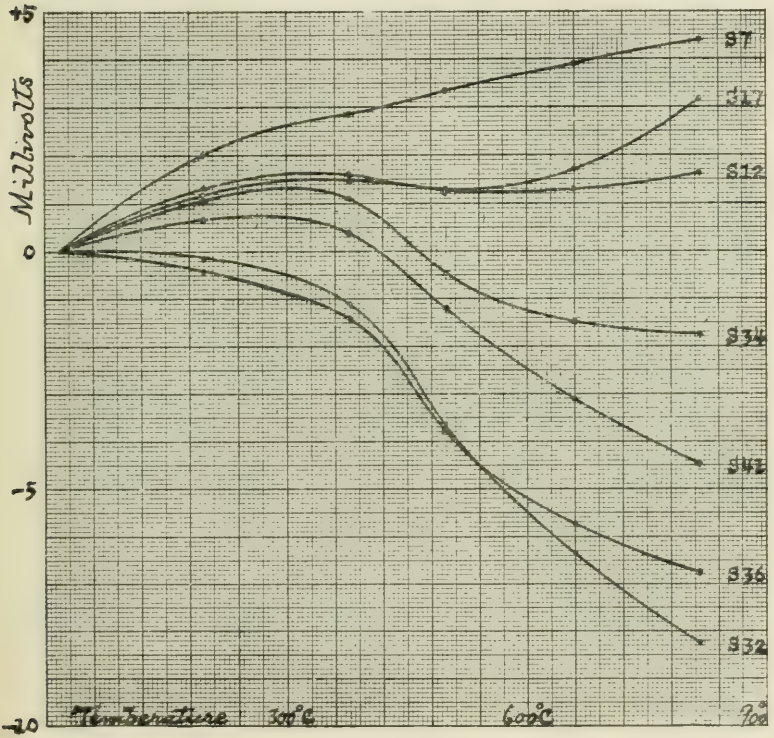

PLATE II. Copper-Nickel-Chromium Alloys.

By the term "standard iron" in this paper we mean a soft iron of low carbon content which gives 47.40 millivolts at 1,500° F. (815° C.), cold junction 0° F. (—18° C.), against a standard constantan wire.

The measurements of E. M. F. were made on a Wolff potentiometer.

EXPERIMENTAL RESULTS.

1. Nickel-Chromium Alloys.

Table I contains the data obtained for the thermo-electromotive force of nickel and nickel-chromium alloys against standard

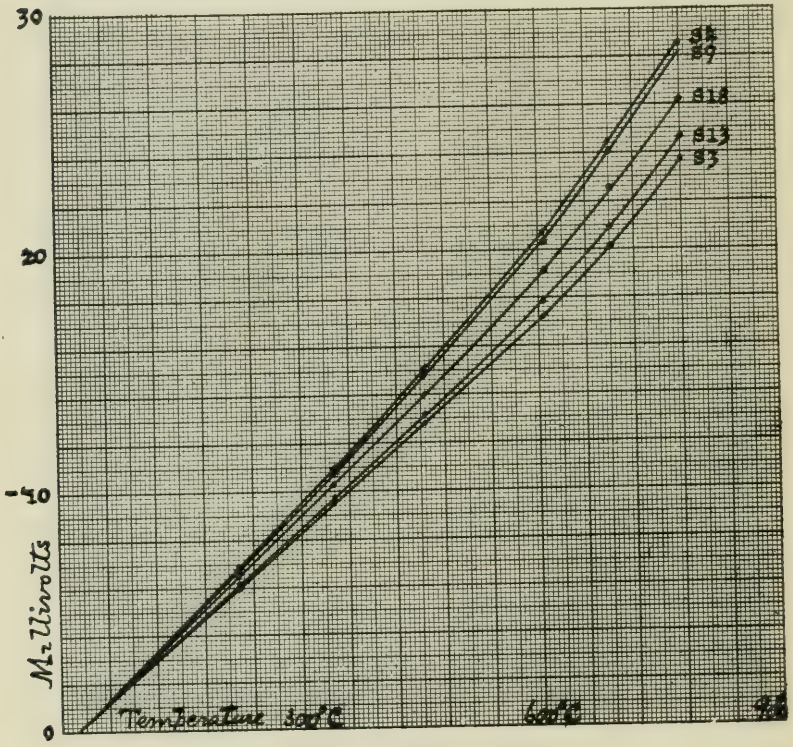

PLATE III. Copper-Nickel-Chromium Alloys.

iron at various temperatures. The nickel wire was obtained by rolling and drawing a piece of electrolytic nickel. The electrolytic nickel was so soft that it did not require to be melted before being drawn.

The effect of the addition of various quantities of chromium is shown in Plate I.

TABLE I. *Nickel-Chromium Alloys.*

Alloy	Composition		Temperature in °C. of Hot Junction					
	Ni	Cr	135	311	492	667	706	834
Electrolytic Nickel[5]	100	0	+4.39	+9.01	+11.93	+15.54	.....	+19.79
S16	100	5	—1.35	—4.19	—8.13	—11.24	—11.76	—12.92
S11	100	10	—1.61	—4.72	—8.98	—13.01	—13.70	—15.61
S6	100	15	—0.92	—3.32	—7.06	—10.69	—11.38	—13.34
S30	100	20	—0.20	—1.80	—4.75	—7.83	—8.45	—10.17
A18	100	25	+0.15	—1.01	—3.45	—6.06	—6.58	—8.00

[5] *Cf.* Harrison: Phil. Mag., 1902 [6], 3, 177-195.

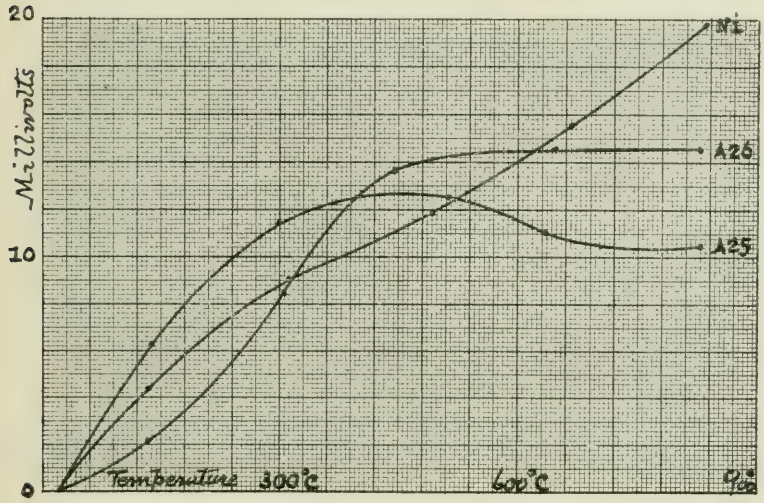

PLATE IV. Iron-Nickel Alloys.

2. *Copper-Nickel-Chromium Alloys.*

Tables II and III contain the measurements of thermo-electromotive force of various combinations of copper, nickel and chromium against standard iron.

Plate II shows marked inversion points in those alloys which contain a high nickel content.

In Plate III the E. M. F.-temperature curves of alloys containing 50 Cu 50 Ni, and 75 Cu 25 Ni are shown to be approximately straight lines.

TABLE II. *Copper-Nickel-Chromium Alloys.*

Alloy	Composition			Temperature in °C. of Hot Junction				
	Cu	Ni	Cr	198	315	496	662	814
S17	25	75	5	+1.21	+1.48	+1.27	+1.70	+3.19
S12	25	75	10	+1.27	+1.57	+1.30	+1.30	+1.62
S7	25	75	15	+2.01	+2.85	+3.35	+3.88	+4.41
S34	20	80	20	+1.04	+1.11	—0.49	—1.46	—1.72
S36	15	85	10	—0.40	—1.39	—3.78	—5.76	—6.75
S32	5	95	20	—0.16	—1.10	—3.71	—6.39	—8.22
S38	16	84	25	+1.17	+1.30	—0.01	—1.11	—1.61
S41	10	90	25	+0.69	+0.37	—1.22	—3.06	—4.47

TABLE III. *Copper-Nickel-Chromium Alloys.*

Alloy	Composition			Temperature in °C. of Hot Junction					
	Cu	Ni	Cr	222	340	456	605	692	783
S9	75	25	15	+6.73	+10.76	+14.80	+20.35	+24.07	+28.09
S4	75	25	20	+6.84	+10.97	+15.06	+20.71	+24.42	+28.52
S18	50	50	5	+6.47	+10.29	+14.00	+19.17	+22.55	+26.18
S13	50	50	10	+6.18	+9.74	+13.18	+17.81	+20.92	+24.61
S3	50	50	20	+6.08	+9.54	+12.78	+17.17	+20.13	+23.63

3. *Copper-Chromium Alloys.*

The E. M. F. of copper-chromium alloys against standard iron are shown in Table IV:

TABLE IV. *Copper-Chromium Alloys.*

Alloy	Composition		Temperature in °C. of Hot Junction		
	Cu	Cr	400	588	760
S20	100	5	+1.30	—0.19	—1.39
S10	100	15	+2.09	+0.66	—0.49
S5	100	20	+1.20	—0.39	.....

The wire *S5* at 760° C. was oxidized through and developed an extremely high negative electromotive force. On cooling the following measurements were obtained:

Temperature °C.	E. M. F. Against Iron
775	—80.47
760	—74.76
565	—41.97
492	—37.80
390	—15.10
382	—14.30

The high E. M. F. is to be attributed to the production by oxidation of a thermo-couple consisting of copper and chromium oxides against metallic iron. The further development of this observation is under consideration.

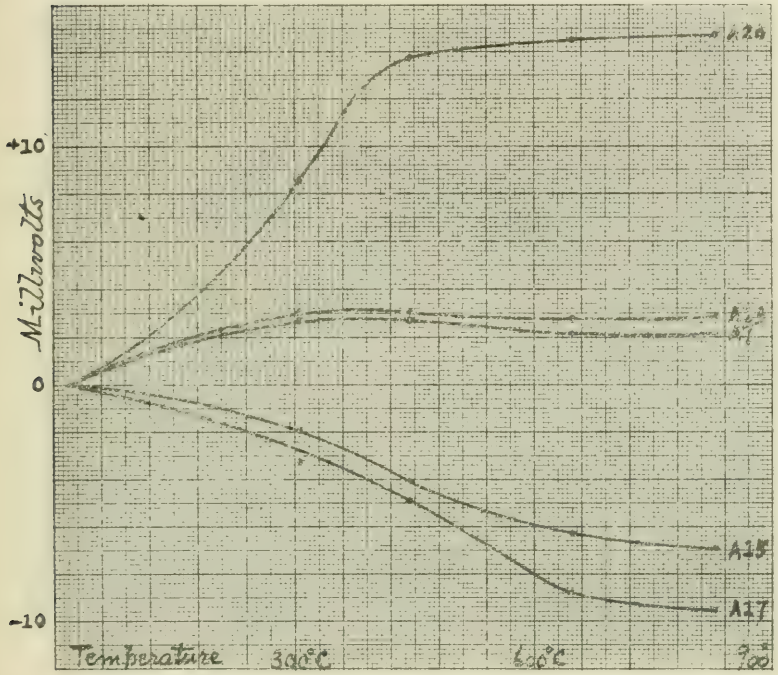

PLATE V. Iron-Nickel-Chromium Alloys.

4. Iron-Nickel-Chromium and Iron-Chromium Alloys

The E. M. F. of iron-chromium and iron-nickel-chromium alloys are given in Tables V and VI.

In Plate IV, the E. M. F.-temperature curves for 100 Ni:0 Fe, 50 Ni:50 Fe, and 25 Ni:75 Fe are shown.

In Plate V, *A26* is the curve for 25 Ni:75 Fe, *A13* and *A7* the curves for 25 Ni:75 Fe with varying amounts of chromium, and *A15* and *A17* the curves for 0 Ni:100 Fe with varying chromium additions.

In Plate VI, *A25* is the curve for 50 Ni:50 Fe, while *A9* and *A12* are the curves for 50 Ni:50 Fe with chromium additions. *A11, A1* and *A5* are the curves for 75 Ni:25 Fe with chromium additions.

It will be readily seen that all alloys of ferro-nickel with chromium show inversion points more or less marked. The curves for alloys of composition 25 Ni:75 Fe with or without chromium are approximately parallel to the abscissa axis after 400° C.

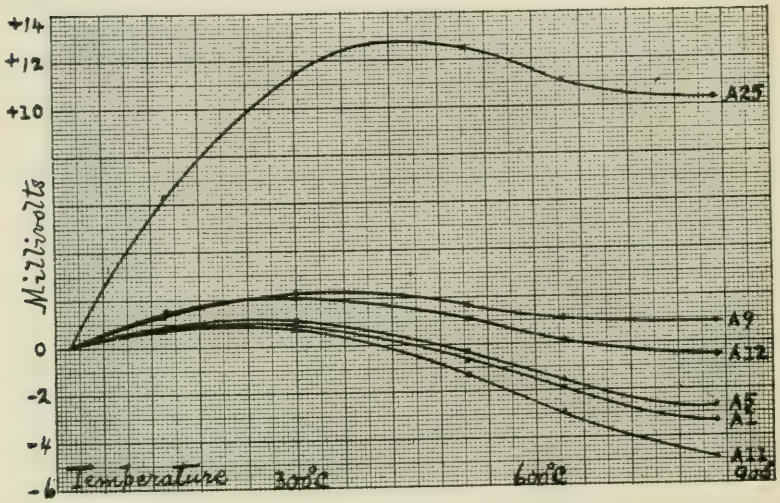

PLATE VI. Iron-Nickel-Chromium Alloys.

TABLE V. *Iron-Nickel-Chromium Alloys.*

Alloy	Composition			Temperature in °C. of Hot Junction			
	Fe	Ni	Cr	305	445	646	830
A17	100	0	10	—3.26	—5.81	—8.78	—9.53
A16	100	0	15	—2.67	—4.43	—6.28	—6.83
A15	100	0	20	—1.96	—4.02	—6.23	—6.90
A14	100	0	25	—1.96	—3.91	—6.30	—7.11
A26	75	25	0	+8.50	+13.69	+14.48	+14.57
A13	75	25	10	+2.97	+3.02	+2.74	+2.83
A10	75	25	15	+2.98	+3.00	+2.78	+2.94
A4	75	25	20	+2.70	+2.79	+2.49	+2.61
A7	75	25	25	+2.73	+2.68	+2.16	+2.14

TABLE VI. *Iron-Nickel-Chromium Alloys.*

Alloy	Composition			Temperature in °C. of Hot Junction				
	Fe	Ni	Cr	138	300	518	637	829
A25	50	50	0	+6.25	+11.45	+12.54	+11.05	+10.46
A12	50	50	10	+1.43	+2.11	+1.14	+0.16	—0.54
A9	50	50	15	+1.37	+2.18	+1.68	+1.09	+0.86
A2	50	50	20	+1.22	+1.81	+1.04	+0.26	—0.27
A6	50	50	25	+1.29	+2.00	+1.46	+0.76	+0.33
A11	25	75	10	+0.87	+0.78	—1.28	—2.99	—4.90
A8	25	75	15	+0.80	+0.63	—1.23	—2.81	—4.47
A1	25	75	20	+0.86	+0.88	—0.68	—1.95	—3.28
A5	25	75	25	+0.91	+1.02	—0.36	—1.57	—2.77

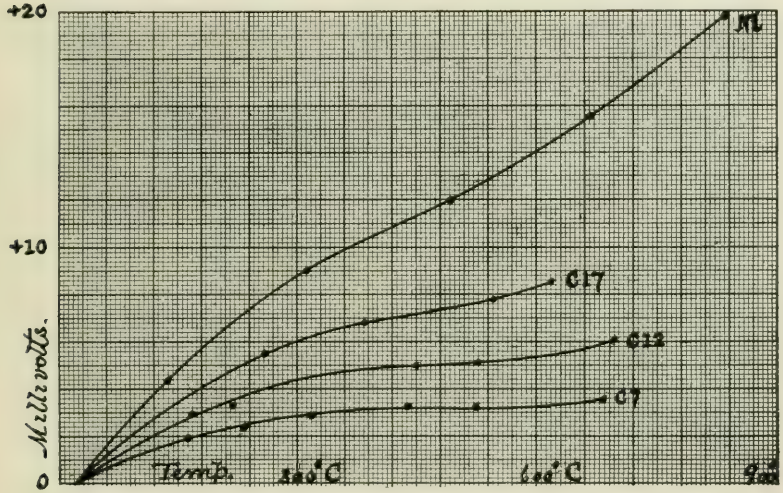

PLATE VII. Nickel-Manganese Alloys.

5. *Nickel-Manganese Alloys.*

The composition of the alloys taken was as follows:

Alloy	Ni	Mn
C17	100	10
C12	100	15
C7	100	20

The E. M. F.-temperature curves for these alloys, together with that for electrolytic nickel, are shown on Plate VII. The

curves are symmetrical and show an E. M. F. which bears an inverse relation to the manganese added. An alloy containing approximately 27 parts of Mn should read zero against iron if this same proportionality held.

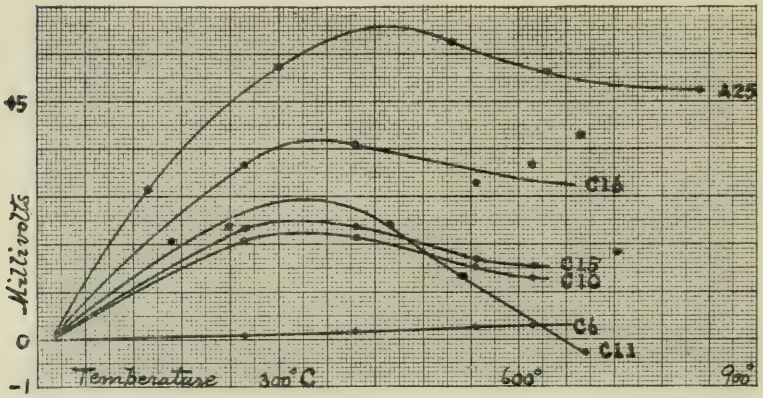

PLATE VIII. Iron-Nickel-Manganese Alloys.

6. *Iron-Nickel-Manganese Alloys.*

The E. M. F.-temperature curves of iron-nickel-manganese alloys are shown on Plate VIII. The composition of the alloys is as follows:

Alloy	Fe	Ni	Mn
C16	25	75	10
C11	25	75	15
C6	25	75	20

Of these *C11* appears to be an irregular curve. No other manganese alloy made showed a similar trend. On the same plate are plotted:

Alloy	Fe	Ni	Mn
A25	50	50	0
C15	50	50	10
C10	50	50	15

Again the curves are symmetrical, but the E. M. F. is not affected in proportion to the amount of manganese added.

On Plate IX are plotted the curves for:

Alloy	Fe	Ni	Mn
A26	75	25	0
C14	75	25	10
H5	75	25	15
H4	75	25	20
C4	75	25	20
C2	75	25	25

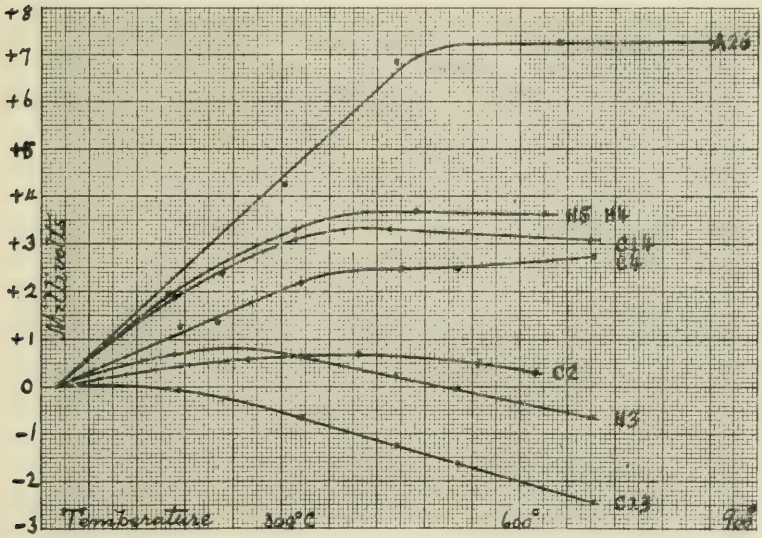

PLATE IX. Iron-Nickel-Manganese Alloys.

7. *Iron-Manganese Alloys.*

Two alloys were tested of the following composition:

Alloy	Fe	Mn
C13	100	10
H3	100	15

The curves are given on Plate IX.

CONCLUSIONS.

In considering the commercial utility of any combination of metals for use in a thermo-couple the following considerations must be borne in mind:

(a) The materials used must be capable of being rolled into rods or drawn into wires.

(b) The E. M. F.-temperature curves must be approximately straight lines with no inversion points.

(c) The materials must be reproducible and must maintain their calibration.

(d) The E. M. F. per degree rise in temperature must be large for high sensitivity.

If the thermo-couple is to be used at high temperatures this last factor is of secondary importance, but two other conditions must be met.

(e) The materials must have a high melting point.

(f) The materials must be resistant to oxidation.

Of the materials now on the market the most widely used are iron-constantan and nickel aluminum-nickel chromium. The former is a satisfactory thermo-couple below 1,000° C. The chief cause of its failure lies in the rapid oxidation of the iron element of the thermo-couple. The E. M. F. of the couple is high and varies almost as a straight-line function of the temperature. Further, it holds its calibration well under successive heating and cooling. The latter couple can be used for higher temperatures (possibly 1,400° C.). The E. M. F.-temperature curve is, however, not as good as that of the iron-constantan couple. Further, the original calibration curve is not so satisfactorily maintained.[6]

The reproducibility of a rod or wire for a thermo-couple is intimately connected with homogeneity in the material. Pure metals would meet this condition best. Solid solutions and eutectic mixtures would follow in order.[7]

[6] Kowalke: Trans. Am. Electrochem., 1913, 24, 337.
[7] Kowalke: Trans. Am. Electrochem., 1914, 26, 199.

However, the electrolytic nickel which was used in our experiments became so brittle at the end of four hours' heating at 800° C. that it broke of its own accord in the furnace. The wire was 0.07 cm. in diameter and showed only a superficial oxidation. The brittleness due to crystalline growth, combined with the irregularity of the E. M. F.-temperature curve due to transformation changes in the metal, excludes it from the category of useful materials.

Of the alloys used in the above experiments all of them are in the class of solid solutions and might therefore be considered as having possibilities of usefulness.

From the point of view of the regularity of the E. M. F.-temperature curves we can, however, exclude the alloys of iron and nickel (Plate IV), the alloys of iron nickel and chromium (Plates V and VI), and the alloys of copper nickel and chromium containing Cu 25 :Ni 75 (Plate II). Further, all the manganese alloys (Plates VII, VIII and IX) would be of doubtful utility by reason of the excessive oxidation of a manganese alloy at high temperatures.

This would leave us with two classes of useful alloys. The first class—nickel-chromium alloys (Plate I)—is already well known. The second class—copper-nickel-chromium alloys Plate III)—will meet all the conditions which have been laid down for a satisfactory thermo-couple. The curves are approximately straight lines. The materials have a high melting point and resist oxidation well. Further, large variations in composition have but little effect on the E. M. F. The copper-nickel concentration can vary between 75 Cu:25 Ni and 50 Cu:50 Ni. The maximum E. M. F. would probably be obtained by using an alloy of 60 Cu :40 Ni and adding chromium thereto.

Finally, it may be said that when all the various factors which influence the choice of two materials for a thermo-couple are considered, these experiments have disclosed that the best combination among those tried would be one containing Cu 50 :Ni 50 :Cr 20 (*S3*) or Cu 50 :Ni 50 :Cr 10 (*S13*) combined with Ni 100 :Cr 10 (*S11*).

We desire, in conclusion, to thank the Leeds & Northrup Company and Mr. F. E. Bash for their close co-operation during the progress of this work.

Russell Sage Laboratory,
Rensselaer Polytechnic Institute,
Troy N. Y., January 9, 1918.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918, President Fink in the Chair.

A PRECISION METHOD FOR THE DETERMINATION OF GASES IN METALS.[1]

By H. M. Ryder.[2]

Abstract.

The metal to be investigated is mounted as a thin ribbon or filament in an electric-light bulb, which is then evacuated. The temperature of the filament is then raised by an electric current, and the pump being kept going the gases evolved are continually forced out into a collecting tube. The temperature is raised in steps of 50° C. up to the melting point, and the gases evolved at each temperature measured and analyzed. The bulb is water cooled, in order to prevent the glass giving off gases on becoming heated. One or two cubic millimeters of gas can be thus measured and analyzed. Silicon steel was found to give off gas abundantly at the Ar_2 point—730° C. The method of analysis of the gas is novel.—[J. W. R.]

In a consideration of the properties of metals, experimental and theoretical evidence indicates that in many cases contained gases, free or combined, play an important part. Although much work has been done in this connection, few satisfactory relationships have been established between the gas contents and physical properties of metals. Hydrogen is held responsible for the embrittling of pickled steel by some. The proper vacuum treatment of steel may greatly increase its magnetic permeability. A true knowledge of these relations would have an important bearing on the further development of desirable qualities in metals, and particularly in steel.

Most of the work along this line has been of a preliminary nature, giving many clues and establishing many facts, but leaving an enormous amount of important information not definitely de-

[1] Manuscript received April 10, 1918.
[2] Research Chemist, Westinghouse Electric and Mfg. Co.

termined. In this paper a method is described which provides for a more precise study of the phenomena involved. Recent important developments have made possible the building of the apparatus required by this method.

In the past sixty or seventy-five years a large amount of work has been done in the field of gases in metals, all interesting, some very valuable, and some involving obvious fallacies. Gellert Alleman is at present publishing in the Journal of the Franklin Institute a series of papers in which may be found an extremely comprehensive and valuable resumé of the work done along this line up to the present time.

A study of the work already done shows that in only one or two cases have efforts been made to determine any relations between the nature and quantity of the gases obtained from metals and the temperature of evolution, and that this work was rather approximate, due to the lack of satisfactory apparatus. In most cases, too, porcelain tubes were used to contain the specimen and heat applied externally, the heating of the envelope causing in many cases a considerable error. A number of experimenters used specimens of large cross-section, not fusing them, so that a considerable lag must have occurred between the treatment of the surface and the center, if the center received any treatment.

In no case, apparently, has a specimen of small section been heated in a cold envelope, and the relation of the different gases evolved to the temperature been determined. These conditions were considered fundamental for the work in hand.

The apparatus required by this method consists of two general parts, the specimen bulb with provision for the collection of the gases, and the auxiliary system for analyzing them.

The specimen is formed at the present time into a long strip of small cross-section. For iron or steel the dimensions used are approximately 0.25 cm. x 0.038 cm. x 100 cm., and for copper, approximately 0.12 cm. x 0.025 cm. x 210 cm., each weighing in the neighborhood of five grams. The strip, prepared on a machine used for the manufacture of heating conductors, and having therefore a very uniform cross-section, is mounted much as a tungsten lamp filament on light tungsten supports, the whole being sealed in a glass bulb. Tungsten leads form electrical connection through the bulb with the ends of the strip for its direct electrical

heating. Potential leads are also provided near the ends of the specimen strip, which enable the temperature of the strip to be determined from its resistance change, the relation between temperature and resistance having been previously determined up to the melting point, for the material of the specimen. A small thermocouple may also be used for the temperature determinations. The bulb itself is inclosed in a water jacket, which serves to keep it at a temperature of from 8° C. to 10° C. during the testing.

This bulb is then sealed, on an all-glass system, to a diffusion pump which pumps the gas immediately on its release to a second bulb, where it is stored until ready for analysis. In this manner the gas is kept from the specimen after its release so that there is no possibility of further chemical action due either to the constituents of the specimen or to the heat.

A system probably similar to one reported by Langmuir,[3] separated from the gas storage bulb by a mercury cut-off, has been provided which will enable the accumulated gas to be analyzed for CO, CO_2, H_2O, H_2, N_2, O_2, CH_4. As this system is all glass, no stop-cocks, rubber, or cement being used, no contamination of the gas is possible except from the hard glass system itself, and this is negligible, less than 0.2 cu. mm. of gas, equivalent at atmospheric conditions, being released from the whole system in twenty-four hours.

In the process of analysis, CO_2 and H_2O vapor are first frozen out with liquid air, and the remaining "dry" gases are pumped into a small chamber by means of a modified Töpler pump. The CO_2 is then separated from the water vapor by substituting carbon dioxide snow for the liquid air. The quantity of CO_2 released is determined by measuring with a McLeod gauge the pressure due to it in a volume accurately known. It is then pumped out of the system and the water vapor released by removing the carbon dioxide snow. The pressure due to this is determined by using a mercury U-tube manometer with an optical lever attachment.[4] Oxygen is added to the remaining gases, which have been returned to the main analysis system, and the CO, H_2, and CH_4 burned in a small combustion bulb, a hot platinum filament being used to

[3] Langmuir, Journal of the American Chemical Society, 1912, 34, 2, 1310.

[4] Reported by J. E. Shrader at the Pittsburgh meeting of the American Physical Society, December, 1917.

start the reaction. The CO_2 and H_2O vapor formed are measured as before and the quantity of CO, H_2, and CH_4 determined from this and a knowledge of the decrease in the quantity of the

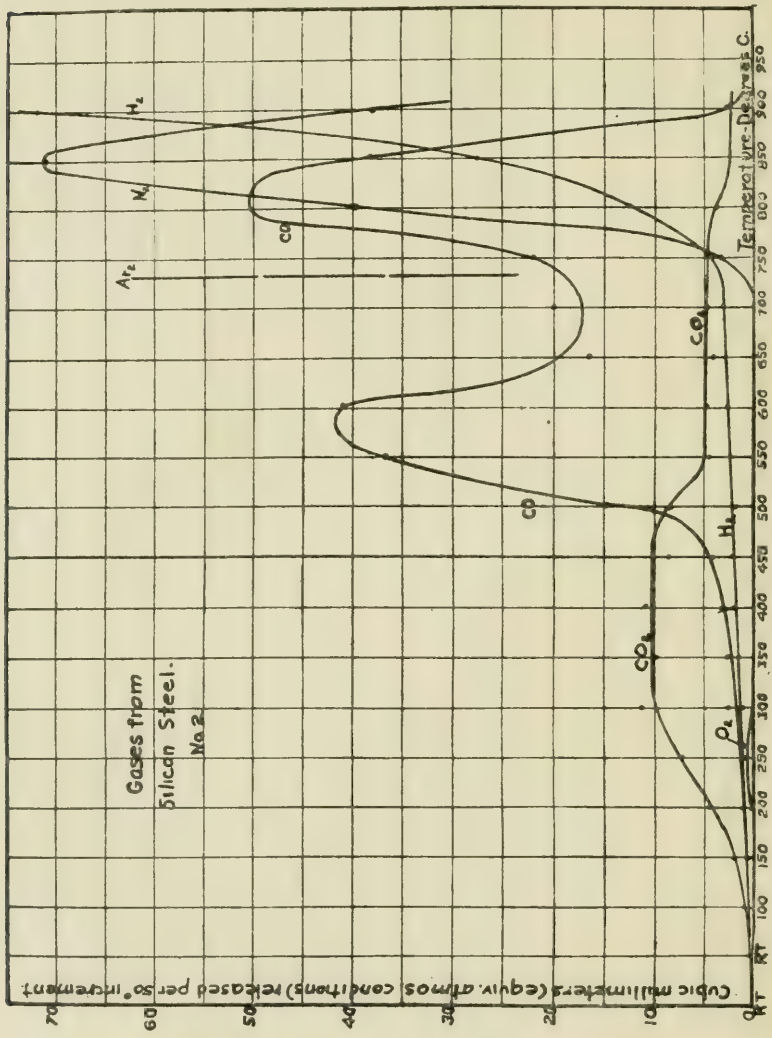

FIG. 1.

mixture of gases. CO added to the remaining gases and burned provides for the determination of the excess oxygen and any oxygen which might be originally present in the gases. Nitrogen

is determined, technically, by difference, but the method permits of a check on its value.

This method, a complete account of which will be published shortly, has been proven by many analyses of known mixtures of gases, and makes it possible to analyze quantities of gas as small as one or two cubic millimeters, measured at atmospheric conditions, with a maximum probable error of 5 percent of the total quantity, or 20 percent to 25 percent of any constituent whose total value is less than 5 percent of the whole. Larger quantities may be analyzed with greater accuracy. The apparatus will take care of any quantity up to that necessary for careful work on a small absorption apparatus.

With the specimen in place in the closed-glass system, the whole is evacuated with diffusion pumps and all the glass is heated to get rid of as much gas as possible from this source. The gas collection bulb is then sealed off (mercury seal) with the specimen bulb and diffusion pump, and released gases from the specimen at room temperature collected for twenty-four hours. This gas is then removed and analyzed and in the meantime the temperature of the specimen is raised to 100° C. and held there for twenty-four hours. The gas released is again collected and analyzed. The temperature is then increased at twenty-four-hour intervals, in 50° increments, until the specimen fuses, analyses being made of the gas collected at each temperature.

Results obtained in this manner show very consistent values from different specimens obtained from the same piece of material. The accompanying curve shows the relation between the temperature of a particular specimen of silicon steel, and the quantity of each gas released per 50° temperature increment. This serves to show the results which may be expected from the use of the method described above. It is interesting to observe that the Ar_2 point for this specimen occurred at about 730° C., which is the point at which very large quantities of carbon monoxide, nitrogen, and hydrogen *began* to be released. A series of such curves is capable of valuable interpretation.

The precision of the method lies in the provision for the elimination of gases from *all* extraneous sources, the use of very thin metal, the practical elimination of end effects in the specimen, and the ability to handle and analyze very small quantities of gas

accurately. All tungsten used has been previously treated in high vacuum at approximately 1,600° C. Tests show that this metal contains little gas originally; and that gas once eliminated but a very small proportion of this amount is re-absorbed on exposure to the atmosphere for some time. By the use of thin metal the lag which must occur when heavy bars are used is eliminated. This elimination has been checked experimentally by the determination of the relation between the rate of evolution of gas and the time, with the temperature of the specimen held constant.

This method, with the problem of the diffusion of gases through metals, which is being carried on with it, makes possible a very thorough study of the gas content of metals, the means of the retention of these gases, and therefore, the more directly, their effect on the physical properties of the metals.

Provision for the complete fusion of the specimen is under consideration, and this will probably be accomplished shortly without any radical change in the principles involved, and without the introduction of any appreciable source of error.

Westinghouse Research Laboratory,
East Pittsburgh, Pa., March, 1918.

DISCUSSION.

J. W. RICHARDS[1]: I regard this as an exceedingly valuable scientific apparatus and procedure, and I believe Mr. Ryder's conclusion, that it will give us a good deal of insight into the constitution of metals and the causes of their failure from gas inclusions, is fully justified.

W. E. RUDER[2]: Early in 1912 the method for the examination of gases in metals developed in this laboratory by Dr. Langmuir (J. Am. Chem. Soc. (1912) **34**, *2*, 1310) and referred to by the author on page 199, was applied to metal strips. As silicon steel happened to be among those tried, it may be of interest to describe here the results obtained.

The method of conducting the experiment was somewhat different from that described by Mr. Ryder, in that the gases evolved

[1] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.
[2] Res. Laboratory, General Electric Co., Schenectady, N. Y.

at two temperatures only were considered, *viz.*, approximately 800° C. and 1100° C.

The vacuum system and the method of analyzing the gas was essentially the same as described by Mr. Ryder.

The size of the specimen (6 x 0.096 x 0.014 inches = 150 x 2.4 x 0.35 mm.) was about $\frac{1}{5}$ that used by Mr. Ryder (volume = 0.13 cub. cm.).

The analysis of the gases on the first heating (800° C.) was as follows:

	Vol. cub. mm.	Percentage
Total gas evolved	34.3	100
Carbon dioxide	13.3	39
Carbon monoxide	17.1	50
Hydrogen	2.8	8
Nitrogen (by difference)	1.1	3

The analysis of gases on the second heating (1100° C.) follows:

	Vol. cub. mm.	Percentage
Total gas evolved	9.4	100
Carbon dioxide	0.1	1.0
Carbon monoxide	1.7	18.0
Nitrogen (by difference)	7.6	81.0

The results were not calculated on the same basis as those obtained by Mr. Ryder, so a direct quantitative comparison is difficult. There is an agreement, however, in that most of the gases evolved at temperatures up to 800° C. are CO and CO_2 with a small quantity of H_2. At higher temperatures, N_2 is the chief constituent, with CO second in volume.

The results disagree most markedly in the amount of H_2 evolved. Our experience has been that when O_2 is admitted for analysis at the higher temperatures, it rapidly disappears without ignition. In one case 54 cub. mm. disappeared in this way. It was undoubtedly absorbed by finely divided iron, which was deposited upon the bulb during the second heating in such quantity as to blacken it quite perceptibly. This conclusion was borne out by the fact that none of the oxygen disappeared in the previous heating.

Is it possible that some such phenomenon might account for the high H_2 value shown in the curve on page 200.

These analyses were carried out by Mr. S. P. Sweetser of the research laboratory of the General Electric Company at Schenectady.

H. M. Ryder (*Communicated*): The work referred to by Mr. Ruder is extremely interesting and the analysis which he offers of the gases obtained from silicon-steel at 800° C. agree very closely with the analyses which I have obtained of total gases released up to this temperature, if water vapor is not considered. Above this temperature, however, there are some fundamental differences, presumably in the method and in the results obtained.

From Mr. Ruder's remarks regarding the disappearance of oxygen it would appear that in the method of Dr. Langmuir the gases to be analyzed as well as those introduced in the course of the analysis are at times in the bulb containing the specimen. If possible sources of error are to be reduced to a minimum, I consider it very necessary to avoid this condition. The finely divided iron deposited on the walls of the bulb is probably chemically very active, as Mr. Ruder suggests and, further, the specimen itself, cold or hot, is in all probability not in equilibrium with any atmosphere, and may absorb a considerable quantity of gas, when placed in contact with it. If the specimen is hot, various chemical reactions may take place. In the apparatus which I have built, a diffusion pump, operating continuously, maintains at all times as high a vacuum as possible in the specimen bulb. The gas is *removed as soon as it is released*. Very few of the gas molecules ever come in contact with the metal specimen after being removed. This effectively prevents the specimen from acting physically, chemically, or as a catalyst, on the released gases. Further, the analyzing system is separated from the specimen bulb and collecting system by means of a mercury cut-off.

Hydrogen was undoubtedly present in large quantities in the gases removed from all the ferrous specimens with which I have worked, at temperatures above the A_2 point. Very pure iron shows the same conditions as silicon-steel, as regards hydrogen, except that the temperature is shifted exactly with the A_2 point. In the case of copper, practically no hydrogen is evolved at these higher temperatures.

I believe that the experimental evidence mentioned briefly here is sufficient to show that the analytical results from the gases released at higher temperatures are in no way affected by the condition of the specimen itself.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918. President Fink in the Chair.

THE ELECTRICAL RESISTIVITY OF PORCELAIN AND MAGNESIA AT HIGH TEMPERATURES.[1]

By P. H. Brace.[2]

Abstract.

Tests of the electrical resistivity up to 1,000° C. of (1) calcined magnesite (impure magnesia) completely fused in an arc furnace and free from cracks and blow-holes, (2) molded calcined magnesite baked at 1,700° C., (3) porcelain such as is used for spark-plug insulators, using direct current. The magnesia had greater resistivity than the porcelain. Uni-lateral effects due to the direct current were noted, and the porcelain gave back electromotive forces up to 0.7 volt. [J. W. R.]

Introductory.

The work here recorded was done in response to a demand for material having a high insulation value at temperatures near 1,000° C.

A considerable amount of work has been done in this country and abroad upon the high-temperature resistivity of refractory materials. Northrup and others have investigated various substances up to 1,600° C., and Somerville has studied the apparent storage of electrical energy by heated refractory bodies when subjected to a steady direct voltage. Most investigators have been chiefly interested in conduction at the high temperatures, but in the present case the interest centered about the insulating value of the materials at 800° C. to 1,000° C.

The application of electrical energy to heating operations in-

[1] Manuscript received April 10, 1918.

[2] Research Chemist, Westinghouse Electric & Mfg. Co.

volving moderate temperatures is increasing, and the tendency is toward the use of higher voltages. There are a number of instances where the conditions demand materials having high insulating value in the neighborhood of 1,000° C., and the problem

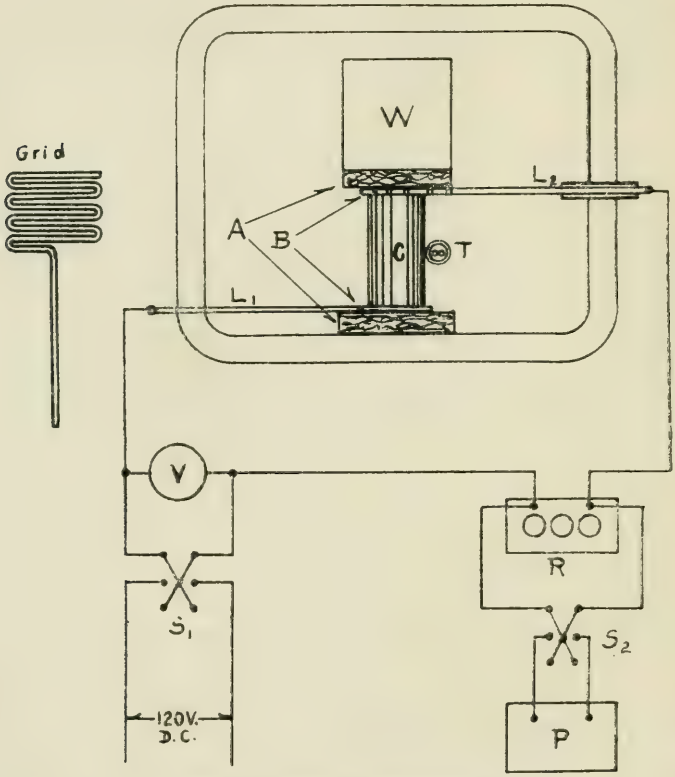

FIG. 1. Diagram of Connections.

of securing adequate electrical insulation even at 800° C. is one requiring attention.

In a particular case it was found that porcelain of the sort used for spark-plug insulators was unsatisfactory because of current leakage at temperatures near 1,000° C., and the tests described below were made to determine the relative insulating value of this porcelain and electrically fused magnesia.

MATERIALS AND TEST PIECES.

Sample No. 1: Electrically fused magnesia.—The material was fairly pure calcined magnesite, the samples used having the following composition:

MgO	94.10 percent
Fe_2O_3	1.46 percent
SiO_2	4.25 percent

The magnesia had been completely liquefied in an arc furnace. From a piece of the fused material, free from cracks and blowholes, the test piece was ground, in the form of a rectangular prism 1.37 in. (3.49 cm.) long, and having a cross-section of 0.673 sq. in. (4.34 sq. cm.).

Sample No. 2: Electrically fused magnesia.—The material was the same as for No. 1. The sample was prepared by crushing the material, molding under heavy pressure, and firing at a temperature above 1,700° C. Its length was 1.02 in. (2.51 cm.) and the cross-sectional area 0.951 sq. in. (6.14 sq. cm.).

Sample No. 3: Porcelain.—This was a cylindrical piece of porcelain of the kind used in making spark-plug insulators. The length was 1.18 in. (3.12 cm.) and the cross-sectional area 0.527 sq. in. (3.40 sq. cm.).

Apparatus.—A wire-wound Hoskins muffle furnace was used for heating the samples, with a platinum: platinum-rhodium thermocouple and a Leeds and Northrup potentiometer for temperature measurements. A Weston D'Arsonval-type voltmeter indicated the voltage applied to the samples. A potentiometer and known high resistance were used for measuring the current through them.

The notation for the diagram of connections, Fig. 1, is given below:

T	Thermocouple
P	Potentiometer
V	Voltmeter
R	Adjustable resistance box
S_1, S_2	Reversing switches
C	Sample
A	Asbestos pads
B	Nickel wire grids
L_1, L_2	Leads to sample

SET-UP OF APPARATUS.

The samples were all heated at the same time. Each sample rested upon a grid of square nickel wire supported by an asbestos pad placed on the floor of the furnace chamber. This arrangement served to give extensive contact area between the grids and the samples, minimizing contact-resistance errors. A nickel wire grid was placed upon the upper end of each sample, then an asbestos pad, and finally a weight of some 11 pounds (5 kg.).

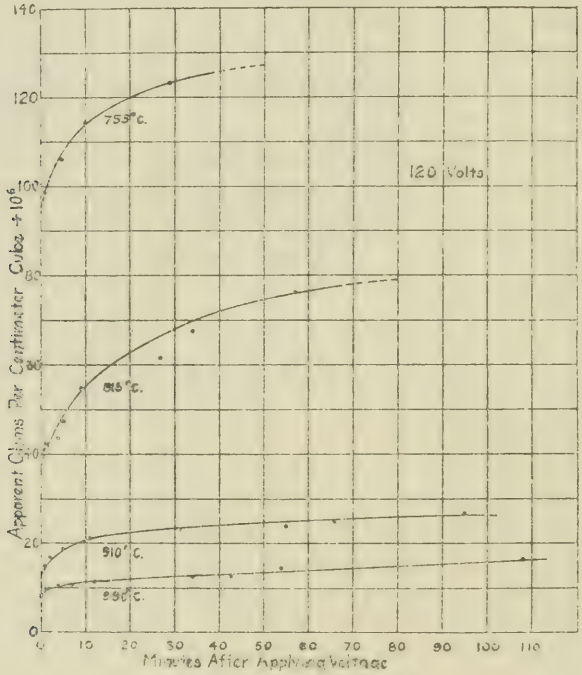

FIG. 2. Magnesia—Fused.

The leads from the upper ends of the samples were brought out of the furnace through silica tubes supported by insulated clamps outside the furnace. No part of the silica tubes or their supports was in contact with any part of the furnace. Errors of measurement due to leakage were thus prevented.

The reversing switch S_1 controlled the voltage applied to the samples, and the switch S_2 the potentiometer connections to the resistance box R.

METHOD.

The method was as follows: The samples were heated for twenty-four hours at 1,000° C. and allowed to cool quickly before starting the series of test runs. Then the temperature was adjusted to a desired value and time allowed for attaining uniformity. A steady voltage was then applied to a sample and the current through it determined at intervals over a considerable

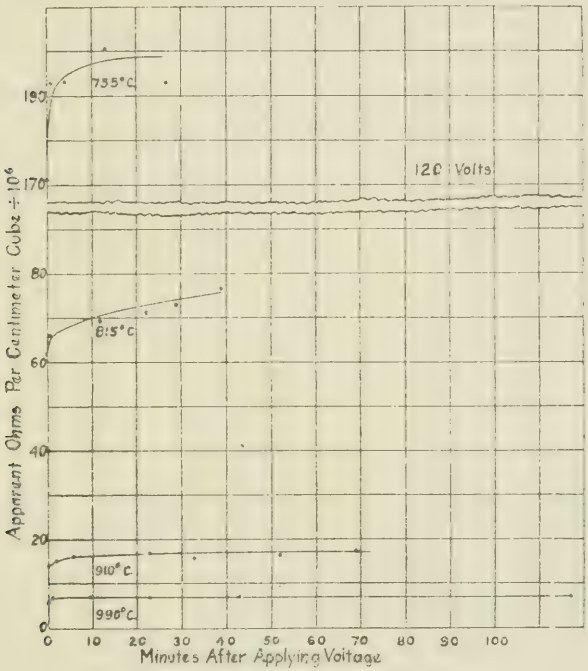

FIG. 3. Magnesia—Molded.

period of time. A sufficient number of values having been obtained, the current was reversed and another set of readings taken as before. Thus, two sets of readings were taken at each temperature with the current through the sample in opposite directions. The temperature was raised to the next value and the above procedure repeated.

The precision of the measurements varied from approximately 10 percent at the higher values of resistivity to better than 1 percent at the lower.

RESULTS.

The results are shown by the curves in Figs. 2, 3 and 4. Only one curve was drawn for each temperature, both sets of values being used.

It will be noted that the apparent resistivity in any given case is a function of the time during which the application of the test

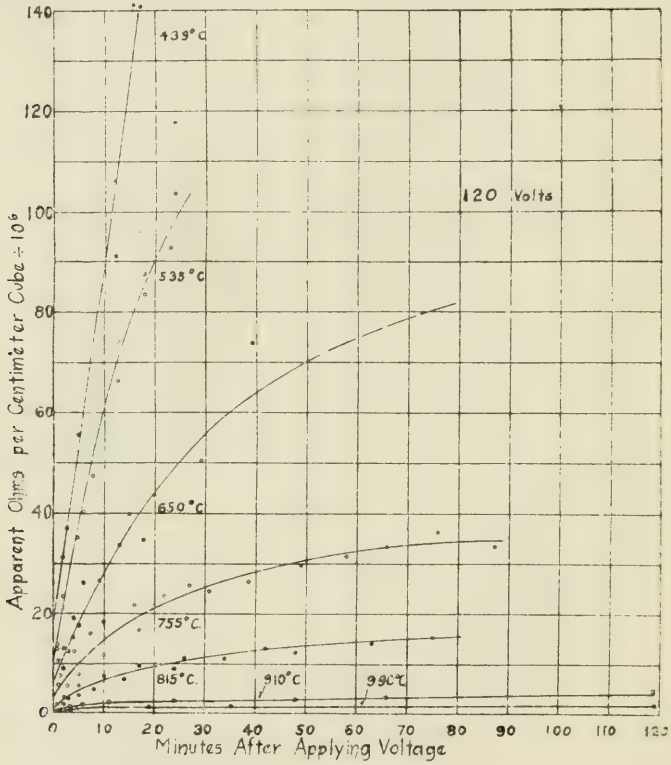

FIG. 4. Porcelain.

voltage continued, and that the final value was in some cases several times the initial value. Similar behavior is exhibited by many insulating materials at ordinary temperatures.

When the voltage was reversed after the resistance had become nearly constant, a low value was found, this value rising with time as at first. Repeated reversals had the same result. The

resistivities to alternating current would approximate the values given by the intersections of the curves with the axis of ordinates.

It is worthy of note that when compared with porcelain, the relatively simple material, calcined magnesite, showed the following characteristics:

1. Higher resistivity.
2. Higher ratio of initial to final resistivity at each temperature.
3. Resistivity comes to steady value more quickly.

These characteristics suggest the behavior of a non-conducting solvent, such as pure water, for example, when substances are dissolved in it. The greater the number and amount of dissolved substances, within limits, the greater the conductivity of the solution and the greater its change with temperature. The porcelain is a complex mixture of mutually soluble oxides, while the magnesia is a relatively pure material. When one recalls the very large increases in conductivity produced by dissolving small quantities of substances in water, and the use of complex salt mixtures to increase the conductivity of non-aqueous electrolytes, it appears likely that the best materials for high-temperature insulation will be found among the pure refractory oxides, of which magnesium oxide is an example.

The two samples of magnesia show nearly the same characteristics, though the molded sample shows somewhat lower values of resistivity. Possibly additional impurities were introduced during grinding and firing.

At the two highest temperatures the porcelain was found to behave like a storage battery. Upon disconnecting the test voltage an electromotive force in the opposite direction was found which was sufficient to force a measurable current through the sample. The electromotive force decayed slowly and was still appreciable after half an hour. The initial value was in the neighborhood of 0.7 volt. This behavior, too, suggests ordinary electrolytic phenomena.

SUMMARY AND CONCLUSIONS.

The apparent resistivity of samples of electrically fused magnesia and porcelain have been measured in the temperature range from 439° to 990° C.

The magnesia was found to have higher resistivity than porcelain at all temperatures investigated.

Applying direct voltage, the apparent resistivity was a function of the duration of the application of the test voltage.

Porcelain was found to exhibit a polarization electromotive force, which at the two highest temperatures was near to 0.7 volt.

Westinghouse Research Laboratory,
East Pittsburgh, Pa., April, 1918.

DISCUSSION.

E. C. SULLIVAN[1]: There is one point which the author's curves show, which he does not discuss, *viz.*, that in the case of each material the change in resistivity with time was very much less at high temperatures than at low. If you will notice the curves in the paper, magnesia, for instance, at 990° gives, in the case of the molded material, practically a horizontal line; at 755° there is a very decided increase in resistivity with time. The same thing is true of the other materials. Just why there should be this difference with temperature is something on which I would like to hear the opinion of the members.

C. G. FINK[2]: This paper covers a subject I have been interested in for some time. About a year ago I presented a paper[3] on the relation between chemical composition and electrical conductivity, and my findings there account for the behavior of porcelain and magnesia as reported in the paper by Mr. Brace. I note that the author does not say how he fired or calcined the magnesia at 1700°. Does anybody here know in what atmosphere Mr. Brace carried out the firing? Very much is dependent upon the nature of the enveloping gases. There is one and a half per cent of iron oxide present in Mr. Brace's magnesia, and if you are going to use a reducing atmosphere to fire in you will reduce iron oxide to metallic iron. Pure iron melts at 1600° C. If Mr. Brace is going to heat the pellets up to 1700° C., he is going to get the whole granular structure of magnesia interlaced with a thin film of metallic iron and thereby the high electrical resistance

[1] Chief Chemist, Corning Glass Works, Corning, N. Y.
[2] Head of Laboratories, Chile Exploration Co., New York City.
[3] Journ. Phys. Chem., (1917) 21, 32. See also Trans. Am. Electrochem. Soc. (1917) 32, 210.

of pure MgO will be destroyed. This, in part, accounts for the better showing of the molded in comparison with the fused samples, since the fusing was probably accomplished in a CO atmosphere. There is this much about high temperature insulation, that eventually we will have to develop *pure* oxide insulators, that is, get down to making furnace bricks of pure oxides. It is a very expensive proposition at present, but all those familiar with electric furnace work know how different for example a silica brick behaves that has three or four percent of impurities compared to one that has eight or ten percent. We are trying very hard to eliminate these impurities in the electric furnace brick, and I think if Mr. Brace carried out further experiments with very pure magnesium oxide and compared them with results on commercial magnesium oxide, it might lead him to change his raw material.

E. F. NORTHRUP[4]: A large number of measurements have been made to determine the properties and constants of complex materials. Such measurements give empirical information very useful to the users of these materials. But such measurements are generally worthless for furnishing scientific information which leads to an understanding of the underlying reasons for the behavior of matter.

It has always appeared to me that in selecting materials for study, to determine such properties as resistivity, thermal e. m. f. and various mechanical properties, that one should strive to select materials of a simple rather than of a complex chemical structure and as chemically pure as practicable. Such materials as pure fused quartz and the pure oxides of the metals and pure metals should be selected rather than mixed oxides and alloys of doubtful composition. When work is done on such materials and accurate measurements are made, the definite information gained has high scientific value, as well as furnishing data of practical importance.

I would urge that those who plan to make a study of materials, especially if working at high temperatures, select simple materials rather than those of complex chemical structure.

For example: It may be very useful to determine the crushing strength at a high temperature of a particular kind or make of

[4] Palmer Physical Laboratory, Princeton, N. J.

fire-clay brick, but such a determination has only a very limited use and the results obtained are wholly practical and not, in the ordinary acceptation of the word, scientific in character.

P. H. Brace (*Communicated*): In reply to Mr. Sullivan's comment in which he notes that the resistivity reaches approximately a steady value more quickly at high temperatures than low, I can only say that at present there seems to be no explanation that is entirely satisfactory. Recent investigations have shown that conduction under conditions such as are here considered is a complex process, and further data should be at hand before an explanation is attempted.

Mr. Fink has asked how the magnesia was fired. A carbon resistance furnace was used for firing the molded material. The block of fused material required no firing. The porcelain was produced under standard commercial conditions. All the test pieces had been heated to temperatures above 1000° C. for periods aggregating over 48 hours, before tests were made, the object being to oxidize any carbon or iron which might be present. Even were the conductivity affected by any metallic iron present, the temperature co-efficient would be in the wrong direction to account for the effects found.

Mr. Fink speaks of "the better showing of the molded in comparison with the fused samples" in support of his metallic film theory. Inspection of the curves will show that the fused material has the better characteristics at 990° and 910°; approximately the same at 815°; and only at 755° did the molded material show superiority.

I heartily concur with Dr. Northrup's remarks urging the collection of fundamental data upon the chemically pure and simple substances.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 2, 1918, President Fink in the Chair.

CRUSHING STRENGTH OF MAGNESIA-SILICA MIXTURES AT HIGH TEMPERATURES.[1]

By O. L. Kowalke[2] and O. A. Hougen.[3]

Abstract.

Magnesia was mixed with varying proportions of silica, baked at various temperatures, and cylinders of the mixture subjected to pressure in an electrically heated furnace, the pressure being applied by a carbon rod, at carefully measured temperatures. The various mixtures were compared by noting the temperatures at which they were crushed by a given applied pressure. Maximum strength was found in mixtures with 7½ percent silica. The apparatus used is described, and microphotographs shown which explain the theory of the formation of compounds between magnesia and silica at the various temperatures. [J. W. R.]

Magnesia, because of its high melting temperature and strong basic qualities, is one of the most important refractories for electric furnace operation. It has served for crucibles used for melting alloys at high temperatures, especially where it was desired to keep the metal or alloy free from contamination with carbon. Although magnesia melts at 2,800° C.,[4] it becomes mechanically weak and somewhat plastic much below this temperature, so that when used for crucibles it must be backed up by some stronger material. At temperatures above about 1,600° C. a charge of molten iron in a crucible 3 inches by 5 inches high (7.6 cm. by 12.7 cm.) will break through the magnesia, owing to its low mechanical strength.

[1] Manuscript received March 2, 1918.
[2] Professor of Chemical Engineering, University of Wisconsin.
[3] Instructor in Chemical Engineering, University of Wisconsin.
[4] **Kanolt: Bull. Bureau Standards, 10, 295.**

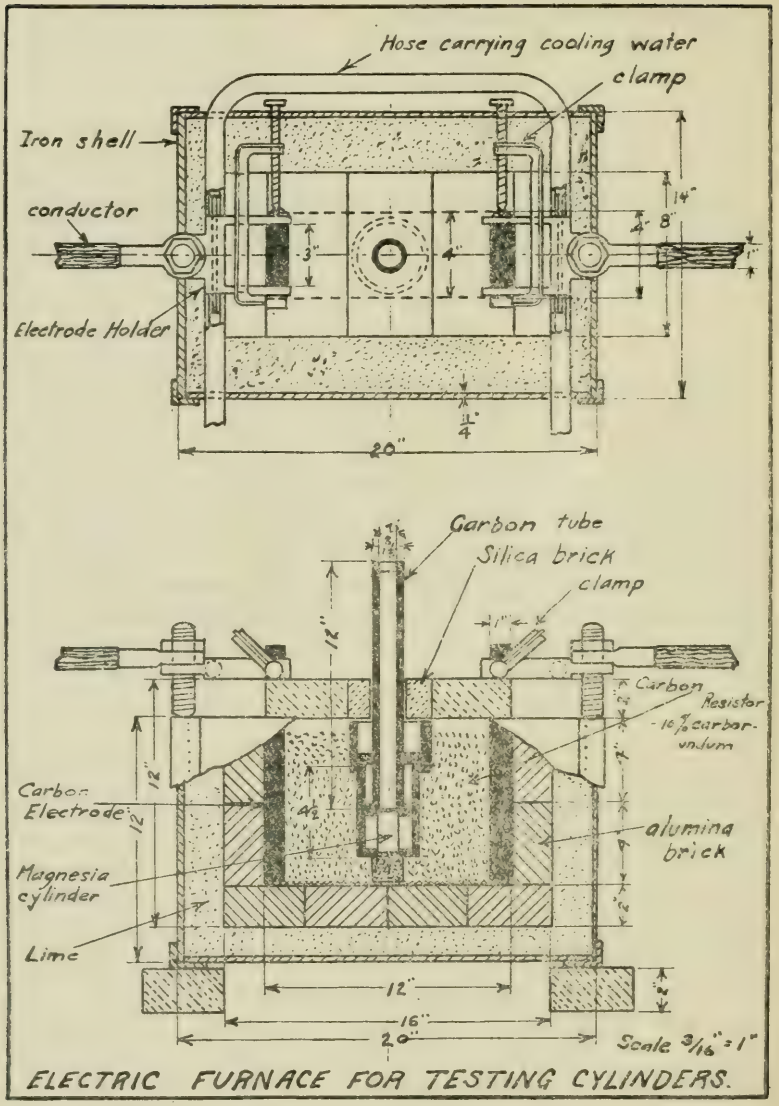

PLATE I.

An investigation was made by one of us to determine whether the addition of various metallic oxides, such as Al_2O_3, Cr_2O_3, TiO_2, SiO_2, ZrO_2, to magnesia would give a mechanical strength

at high temperatures greater than magnesia itself. This preliminary investigation showed that in general there was an increase in mechanical strength. Of all the materials tried, silica gave the best results.

The purpose of this investigation was to determine more closely the influence of silica upon the crushing-strength capacities of silica-magnesia mixtures at high temperatures.

PROCEDURE.

A pure grade of magnesia was prepared from Merck's "Magnesium Oxydatum" by calcining the same in a gas furnace at about 1,500° C. The analysis of the calcined product was: MgO 99.92, Fe_2O_3 0.08, H_2O 0.02. The silica used was obtained from a rather good grade of quartz, which analyzed: SiO_2 97.66, CaO 0.86, Fe_2O_3 0.80, H_2O 0.08.

Both materials were ground to 40-mesh (16 per cm.) in a porcelain ball-mill. After grinding, the two were mixed in the various proportions desired and tumbled again in a porcelain ball-mill to insure intimate mixture. From the mixtures of silica and magnesia test cylinders were made.

The mixtures of silica and magnesia were moistened with 10 percent (an amount found most effective) of their weights of water, and then formed into cylinders in a hydraulic press under a pressure of 1,500 lb. per sq. inch (105 kg. per sq. cm.). They were dried at 100° C., and then baked in a granular carbon resistor furnace to about 2,100° C. After the cylinders had cooled in the furnace, they were ground to a uniform cylindrical form, 1 inch diameter by 2 5/32 inch long (2.54 cm. diameter by 5.5 cm. long), with the ends parallel.

The test cylinders were then put under a uniform static load of 66.5 lb. per sq. in. (4.65 kg. per sq. cm.) and heated at a uniform rate until they failed. The rise in temperature and the temperature at which failure occurred were measured by means of a Holborn-Kurlbaum optical pyrometer.

APPARATUS.

The furnace used for testing the cylinders is shown in Plate I. The resistor consists of carbon plus ten percent of carborundum. The magnesia-silica cylinder under test (*D*, Plate II) rested upon

a graphite block *A* which was held in place by a graphite crucible *B*. The pressure was transmitted to the magnesia cylinder *D*

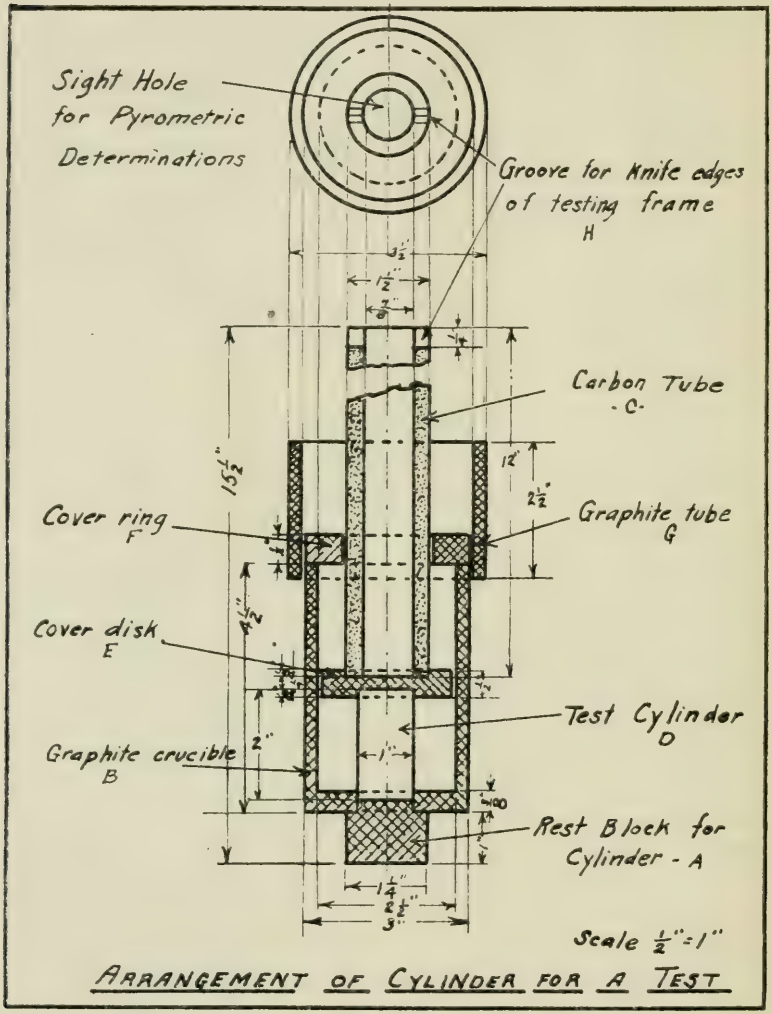
Sight Hole for Pyrometric Determinations
Groove for Knife edges of testing frame H
Carbon Tube C
Cover ring F
Graphite tube G
Cover disk E
Test Cylinder D
Graphite crucible B
Rest Block for Cylinder - A
Scale ½" = 1"
ARRANGEMENT OF CYLINDER FOR A TEST

PLATE II.

through the carbon tube *C* and the graphite disc *E*. Recesses were turned in the disc *E* so that the test cylinder *D* and the carbon tube *C* were held in place. A cover ring of graphite *F* was

placed on top, and another graphite tube *G* was fitted around the crucible *B* to prevent the resistor from falling in.

Pressure was applied to the carbon tube by means of a lever and weight, so arranged that eccentric loading was minimized. The lever was kept as horizontal as possible, and the motion sideways was also restricted, yet freedom of motion in a vertical plane was possible.

The Holborn-Kurlbaum optical pyrometer was mounted on a platform so that the line of sight in the telescope coincided with the axis of the carbon tube *C*, Plate II. The tube *C* served as a "black body" for observing the temperature of the test cylinder. The brightness of the lamp filament in the pyrometer was matched against the brightness of the disc *E* which was ¼ inch (6.5 mm.) thick at the section covering the test cylinder. All carbon and graphite parts used in the temperature measurements were first thoroughly heated to above 2,100° C. to distill off any volatile materials or such as would produce fume. Since the rise in temperature of the furnace was very slow, it was assumed that observations for temperature on the graphite disc would also give the temperature of the test cylinder. The pyrometer was provided with a rotating sectored disc to permit extension of the range without overheating the lamp, and it was calibrated against a carefully calibrated platinum thermo-couple according to the method proposed by Prof. C. E. Mendenhall.[5]

PRELIMINARY TESTS.

After a few tests had been made it was recognized that the rate of heating the cylinders under test had a big influence on the result. The preliminary tests were made in the apparatus just described, but the cylinders were heated rapidly to 1,000° C. and then beyond that to the point of failure at rates varying from 10° to 20° C. per minute But it soon was clear that the rate of heating *below* 1,000° C. affected the results obtained. All temperatures were measured by the optical pyrometer, and since this is not sensitive below 800° C., the results were not satisfactory. The following table shows the irregularity of the results from this procedure.

[5] Mendenhall and Forsythe: Phys. Rev., 1911, **33**, 74.

Crushing Temperature of MgO / SiO_2 Mixtures Under Load.

Percent Silica	Temp. of Failure	Rate of Heating deg./min.	Temp. of Failure	Rate of Heating deg./min.
0	1,682	19	1,684	10
3	1,752	16	....	..
5	2,708	15	....	..
7	1,756	22	1,924	8
9	1,736	20	1,902	12
11	....	..	1,800	13

The manner in which the test specimens failed was quite uniform; it usually occurred by the cylinders bursting out at the middle, with ends telescoping each other.

While the rate of heating affected the results obtained on the magnesia-silica cylinders, it did not affect the results in a similar manner when pure magnesia cylinders were tested. A change in the rate of heating pure magnesia had but little effect on the temperature at which failure occurred. Failure in the magnesia cylinders came on gradually and slowly; in the magnesia-silica cylinders the failure was always abrupt.

FINAL TESTS.

From the preliminary tests it was evident that the addition of six to eight percent silica to magnesia gave a product whose strength at high temperatures was greater than pure magnesia. Owing to irregularity in the baking and testing, the results were open to question. A series of cylinders having amounts of silica varying from zero to twelve percent was made and baked at the same temperature—about 2,100° C. In the load-carrying tests, the temperature for each specimen was raised at a uniform rate of 10° C. per minute, from room temperature to the point of failure. A thermo-couple was used to measure temperatures below 1,000° C., and the optical pyrometer above that point.

The results of these tests are given in the table below. It is apparent that there is a distinct maximum at about seven to eight percent silica. The increase of strength up to eight percent silica

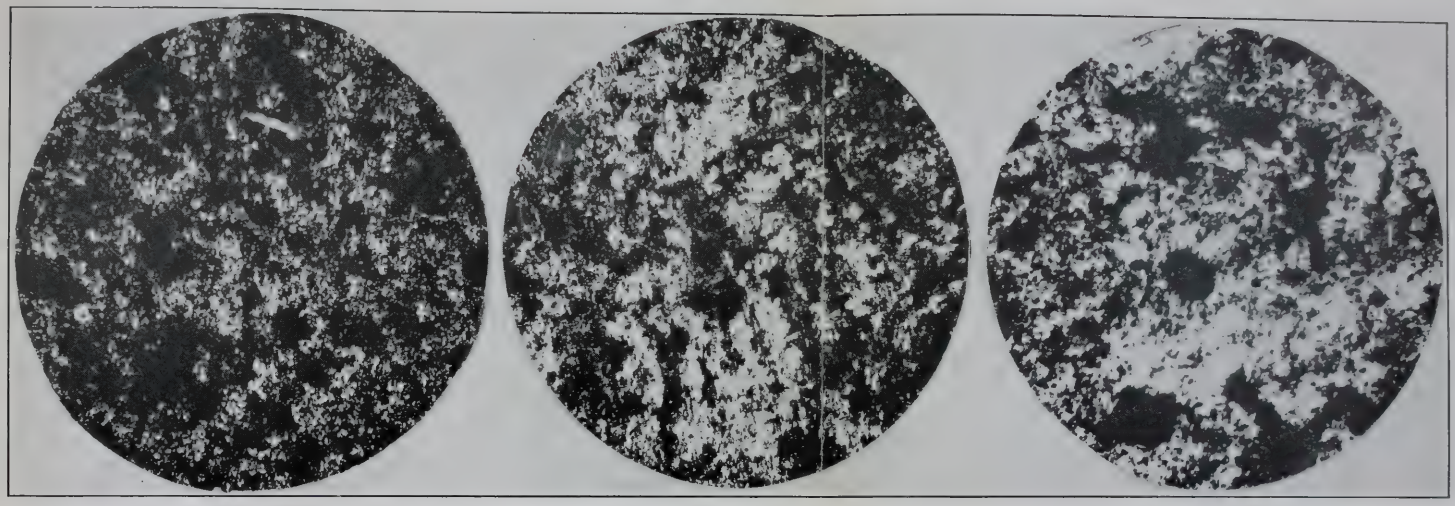

FIG. 1. *c* —baked at 1,900° C.; cooled in furnace.

FIG. 2. *e*—baked at 2,000° C.; held 1 hour above 1,950° C.; cooled in furnace.

FIG. 3. *f*—baked at 2,100° C.; held 1½ hours above 1,950° C.; cooled in furnace.

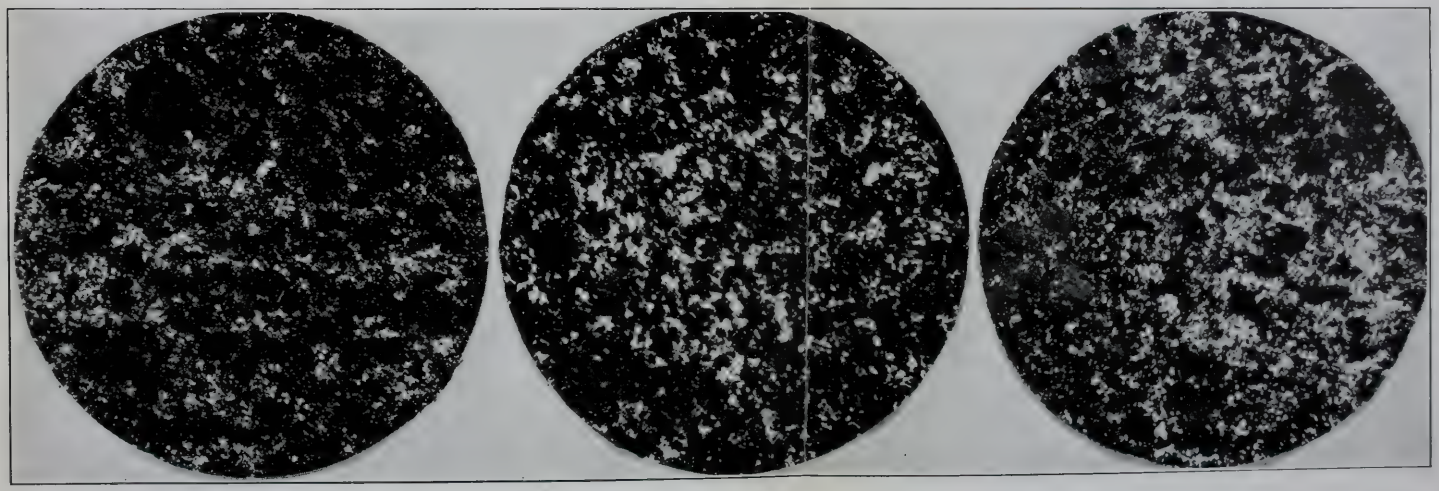

FIG. 4. *A*—baked at 1,800° C.; quenched in cold water.

FIG. 5. *E*—baked at 2,000° C.; held 1 hour above 1,950° C.; quenched in cold water.

FIG. 6. *F*—baked at 2,000° C.; held 1½ hours above 1,950° C.; quenched in cold water.

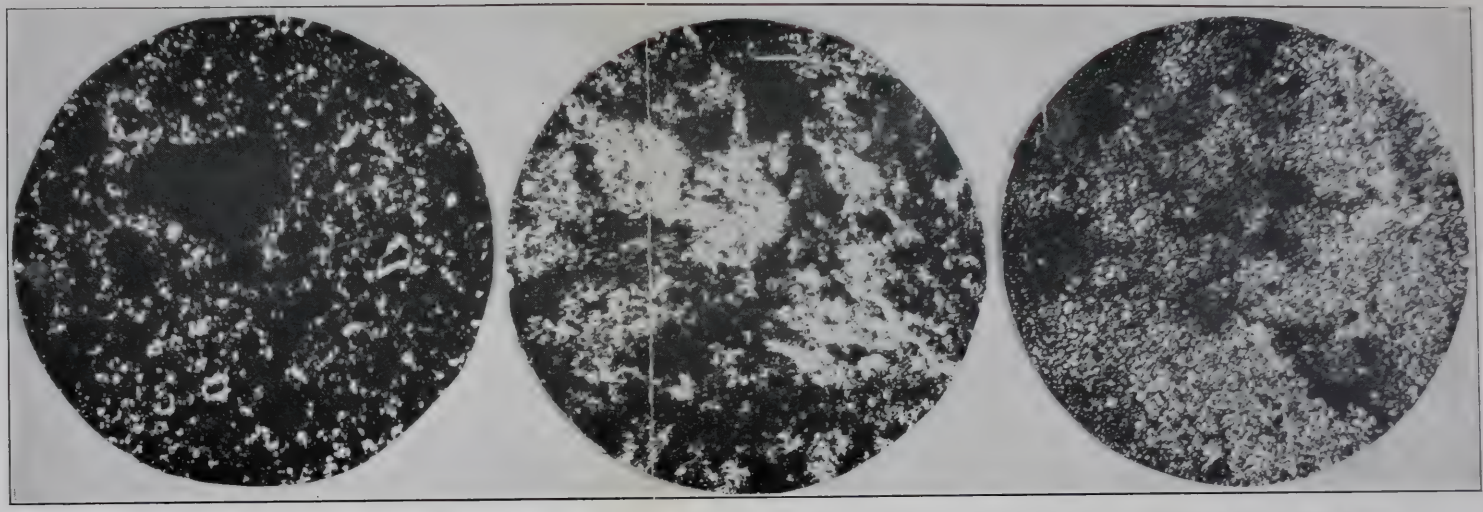

FIG. 7. *g*—baked at 1500° C. for 1 hour.

FIG. 8. *h*—baked at 1,800° C. for 1 hour .

FIG. 9. *i*—baked at 1,960° C. for 1 hour.

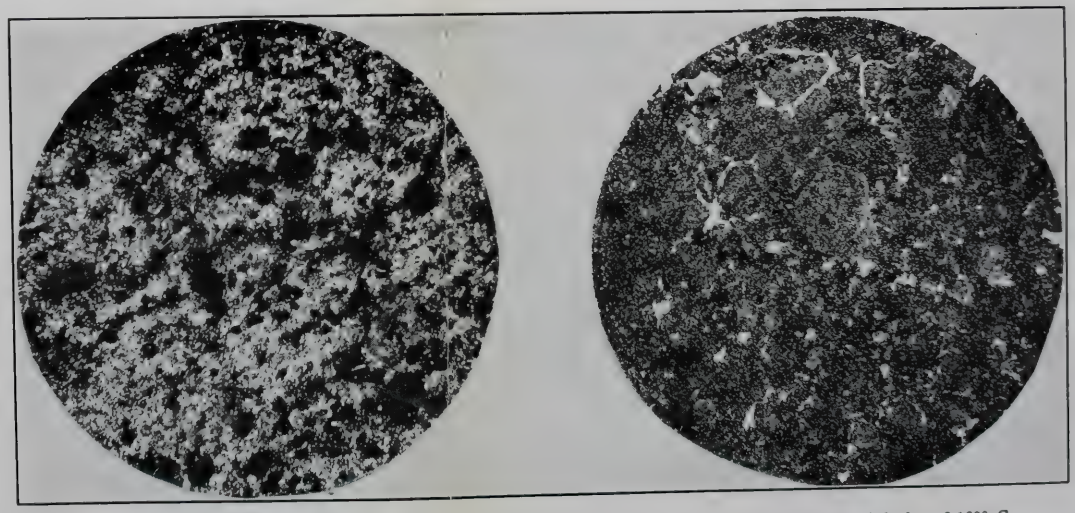

FIG. 10. *j*—baked at 2,200° C. for 1 hour.

FIG. 11. PURE MAGNESIA—baked at 2,120° C.
[40 Diameters—*Unpolarized light.*]

is somewhat more rapid than the decrease in strength beyond that amount. The specimens having 7½ percent silica failed at a temperature 190° C. higher than that for pure magnesia.

Silica Content Percent	Temperature at Failure
0	1,680° C.
3	1,800
6	1,850
7	1,860
7½	1,870
8	1,845
8	1,860
12	1,830
12	1,845

Heat treatment during baking was recognized as an important factor in determining the subsequent strength of the cylinders. A series of cylinders containing 7.5 percent silica was made in the regular manner. The temperature of each cylinder in baking was raised uniformly at the rate of 20° per minute from room temperature to the maximum, and then the maximum was maintained for an hour. Then cooling proceeded slowly in the furnace. Cylinders so treated were baked respectively at 1,500°, 1,800°, 1,950°, and 2,200° C. The cylinders heated to 1,950° C. and 2,200° C. were badly pitted and corroded and showed a low temperature of failure.

Temperature of Baking	Temperature at Failure Under Load
1,500° C.	1,570° C.
1,800	1,820
1,950	1,720
2,200	1,790

The corrosion and pitting noted in the above tests above 1,900° C. made it desirable to study the effect of prolonged heating on the loss in weight. A series of cylinders having approximately 7.3 percent of silica were baked at various temperatures for varying lengths of time and allowed to cool in the furnace. Each cylinder was weighed before and after baking to determine the loss. The results are given in the following table:

Maximum Temperature of Baking	Percent Loss in Weight	Heat Treatment
1,500° C	3.7	1 hour at maximum temp.
1,800	6.1	10 min, " " "
1,800	7.4	1 hour " " "
1,800	8.5	10 min " " "
1,850	7.5	10 " " " "
1,900	9.8	10 " " " "
2,000	14.6	1 hour at 1,950° C.
2,000	17.1	1½ hours above 1,950° C.
2,000	11.0	1 hour at 1,950° C.
2,100	31.7	1½ hours at maximum temp.
2,200	27.0	1 hour at maximum temp.

From this data it will be seen that prolonged heating above 1,900° C. produces a great loss in weight, and that for temperatures above 2,000° C. the loss increases rapidly. In one case of prolonged heating at 2,100° C. complete volatilization of a magnesia-silica mixture resulted, due to the violent action of carbon upon both magnesia and silica. Cylinders baked at 2,100° C. and suddenly quenched in cold water produced a distinct acetylene odor.

Since the above heat treatment proved to be too severe, another set of 7½ percent silica cylinders was baked under less severe treatment. In this baking all cylinders to be heated at 1,800° or above were maintained at 1,800° C. for one hour and then heated at the usual rate, 20° per minute, until the maximum temperature was reached. Data obtained is given herewith.

Maximum Temperature of Baking	Crushing Temperature
1,500° C.	1,570° C.
1,800	1,820
1,850	1,870
2,100	1,900

This data shows that increased temperature and duration of baking increases the subsequent strength of the cylinders, but prolonged heating above 1,900° C. must be avoided, because of the destructive action of carbon upon magnesia.

MICROSCOPIC EXAMINATION.

Thin sections of various cylinders, baked at various temperatures and cooled in various ways, were made, to permit a microscopic examination of the crystallographic structures produced.

The specimens from which the thin sections were taken were all made with 7.5 percent silica. As shown in the table below some were heated to a predetermined maximum temperature, held there for a given period of time, and then quenched in cold water; other cylinders were allowed to cool slowly in the furnace after being brought to the maximum temperatures.

Mark	Maximum Temp. of Baking ° C.	Rate of Heating per Min.	Period of Heating at Max. Temp.	Cooling
A	1,800°	20°	10 min.	Quenched in cold water
B	1,850	"	10 "	" " " "
C	1,900	"	10 "	" " " "
D	1,950	"	10 "	" " " "
E	2,000	"	1 hr. at 1,950° C.	" " " "
F	2,000	"	1½ hrs. above 1,950° C.	" " " "
a	1,800	"	10 min.	Cooled slowly in furnace
b	1,850	"	10 "	" " " "
c	1,950	"	10 "	" " " "
d	1,950	"	10 "	" " " "
e	2,000	"	1 hr. at 1,950° C.	" " " "
f	2,100	"	1½ hrs. above 1,950° C.	" " " "
g	1,500	"	1 hr.	" " " "
h	1,800	"	1 "	" " " "
i	1,960	"	1 "	" " " "
j	2,200	"	1 "	" " " "
k	2,120	40°	(Pure magnesia)	" " " "

In these specimens the minerals Periclase and Forsterite were identified. Below 1,500° C. there is only a slight formation of Forsterite. This mineral is formed first in minute crystals in the grain boundaries of Periclase. As the temperature is raised to between 1,700° C. and 1,800° C. the crystals grow rapidly in number and size, and finally unite to form a complete envelope about the Periclase. Above 2,000° C. this envelope of Forsterite, due to surface tension, collects into separate crystals. Specimens in which the Forsterite had collected into separate crystals failed

under load at a lower temperature than those specimens where the envelope remained intact. This would appear to show that the Forsterite acts as a binder to hold the Periclase together, and that failure comes at a temperature when Forsterite softens.

The microphotographs shown in Plates III and IV were made with polarized light and crossed Nicols. The Periclase is represented by the black areas and the Forsterite by the white; the magnification being about 40 diameters. From Plate IV it is apparent that the Forsterite growth is progressive with a rise in temperature. The quenching operation serves to repress the formation of Forsterite, as shown in Plate III.

Pure magnesia, whose melting point is 2,800° C., has the property of bonding itself at temperatures 1,000° degrees below its melting point, into a hard mass. As shown in Plate IV, made in unpolarized light, the grain boundaries are fairly distinct. This specimen was thicker than the ordinary run of thin rock sections, but the material did not permit of thinner grinding without breaking. This specimen was baked at 2,100° C.; no other specimens of magnesia baked at lower temperatures were examined microscopically.

ACKNOWLEDGMENT.

Grateful acknowledgment is here made to Professors A. N. Winchell and W. J. Mead, of the Department of Geology of the University of Wisconsin, for many suggestions and assistance in identifying the minerals, the use of equipment, and the making of the microphotographs.

CONCLUSIONS.

1. Pure magnesia failed under a load of 66.5 lb. per sq. in. (4.65 kg. per sq. cm.) at a temperature of 1,680° C.

2. The addition of silica to magnesia, with seven to eight per cent silica as a maximum, increased the mechanical load-carrying capacity, so that failure occurred only at about 1,870° C., which is approximately 190 degrees higher than magnesia supported.

3. The failure of magnesia cylinders is slow and gradual; that of magnesia-silica cylinders is abrupt.

4. The superiority of magnesia-silica mixtures with 7½ per cent silica, over pure magnesia, in mechanical load-carrying capa-

city, appears to be due to the envelope of Forsterite, which cements the grains of Periclase.

5. Above 2,000° C. carbon attacks magnesia-silica mixtures very rapidly.

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DISCUSSION.

L. E. SAUNDERS[1]: The experimental work covered in this paper was difficult and has been carried out by very ingenious methods The subject is of importance at the present time, and if the results can be definitely relied on they are an important contribution to knowledge of refractories for use at high temperatures. It is too bad that analytical results are not given for the magnesia-silica mixtures in their various stages. It would be the writer's idea that a mixture of magnesia and silica heated to 2,100° C. would lose some of its silica content in the process. In the heating of the cylinders in contact with carbon it hardly seems likely that the two ingredients, magnesia and silica, would react with the same velocity and that the resulting cylinder after failure would have the same relative composition. For that reason the analytical results on the products would have an important bearing on the trustworthiness of the results. It would have been most interesting to compare a product made from previously molten magnesia and then formed in cylinders and heated to a higher temperature, for its resistance to crushing. It seems probable that a re-assembled material of that character would show greater strength than was the case with the cylinder made from amorphous magnesia and baked at 2,100° C.

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A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

METHODS FOR THE COMMERCIAL ANALYSIS OF FERRO-SILICON.

By Earl M. Anger.[1]

Abstract.

Personal notes and experiences in the commercial analysis of electric-furnace ferro-alloys for carbon, manganese, phosphorus, phosphorus evolved as phosphene, sulphur, iron, titanium, calcium, magnesium, aluminium, barium, and silicon; with advice on sampling.

I have read with much interest papers by a number of writers on the commercial analysis of ferro-silicons of various grades. Each gives long, tedious methods, and not all of the necessary accuracy. Some writers determine several elements and then call the balance silicon. There are several elements which often occur in ferro-silicon of these grades when manufactured from iron ore or iron cinders, which are entirely neglected in this calculation. Any one of these elements may at times contaminate ferro-silicon up to 1 percent. A method will be given in the following pages for the determination of some of these elements.

The elements usually to be determined in ferro-silicon are as follows: Carbon, manganese, phosphorus, sulphur, calcium, magnesium, aluminium, iron, silicon and barium. Many samples examined contain 0.1 to 0.5 percent barium.

The following methods will be found accurate and rapid:

Carbon.

Many samples will give off all the carbon by direct combustion in oxygen at 1,050° C. This temperature is near to the maximum

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heat the nichrome winding will give in the electric combustion furnace. Other samples made from the same materials and of approximately the same composition will not give all their carbon by direct combustion in oxygen. These samples when burned in oxygen gave from 0.1 to 0.4 percent lower carbon than when oxidized by lead peroxide. This error in the carbon determination may occur at any time, and to burn every sample with lead peroxide would prove to be destructive to both the combustion boat and also to the combustion tube. After some experimenting the following method was found to be entirely satisfactory for these alloys, and also proved very satisfactory for oxidizing many other ferro-alloys and refractory materials.

A low-carbon steel of 0.10 percent carbon was used in these determinations. It was placed in a lathe and the turnings between 20 and 30 mesh used for assisting the liberation of carbon. The intense heat produced by oxidizing 2 grams of fine steel greatly accelerates the combustion of the sample which is mixed with it, and liberates its carbon as CO_2.

The method for carbon determination is as follows:

One-half to one gram of finely ground sample was mixed with 2 grams of fine steel turnings and placed in the combustion furnace. Oxygen was turned on to a constant flow through the apparatus. The steel turnings and ferro-silicon must fuse, to give off all the carbon. The CO_2 was absorbed by soda-lime in a Fleming tube. Time taken for the complete determination, 8 minutes. The fusion can be easily lifted from the boat, and causes no more trouble than an ordinary steel combustion. The boats used were made of clay; a Zirkite boat, made by the Foote Mineral Co., was also used.

Manganese.

The following was the method for manganese, using the ammonium persulphate method to finish the determination, as in the steel works laboratory.

One-half to one gram of finely ground sample was placed in a platinum dish, covered with 10 c.c. of dilute nitric acid (1:1), and then slowly dissolved by drops of hydrofluoric acid. When completely dissolved, which will take place in the cold in a few

minutes with silicon 25 to 90 percent, the solution is evaporated to nitrate dryness. Five c.c. of water is added and again evaporated to nitrate dryness. Then 10 c.c. of nitric acid (1:1) is added and the dish heated. The solution, when complete, was transferred to a 100 c.c. Erlenmeyer flask and 15 c.c. of silver nitrate solution added. When boiled down to 15 c.c., 15 c.c. of ammonium persulphate solution (140 grs. per liter) was added, and the permanganic acid developed. This is then titrated with sodium arsenite, after cooling.

Total Phosphorus.

One gram of finely powdered sample is placed in a platinum dish and covered with 30 c.c. of concentrated nitric acid. Then hydrofluoric acid (1:1) is added by drops until the bulk is dissolved. Then concentrated hydrofluoric acid is added until all is dissolved except a small amount of material. All writings on this subject that have come to my notice reject this material as containing no phosphorus. In many samples examined this small amount of material contained as much as 50 to 100 percent of the amount of phosphorus contained in the nitric acid solution.

The nitric acid solution containing the residue is evaporated to dryness (nitrate), then 15 c.c. of concentrated nitric acid added, and taken again to nitrate dryness. The residue is taken up with dilute nitric acid and filtered into an Erlenmeyer flask. The filter is placed in a platinum crucible and burned. The residue is fused with a small amount of sodium carbonate. Hot water is added to the crucible, and, when all except a small amount of precipitate is dissolved, the solution is filtered into the original filtrate, the phosphorus going into the filtrate as sodium phosphate. The acid solution is made acid with nitric acid, one c.c. added in excess, and precipitated as usual with ammonium molybdate.

The fusion with carbonate and leaching out with water also holds in the precipitate some elements which would do harm to the phosphorus determination, and at the same time gives all the phosphorus as sodium phosphate. The dodeca-molybdate is titrated with caustic potash solution and nitric acid. A single determination takes less than an hour.

Phosphorus Liberated as Phosphene.

Phosphorus exists in ferro-silicon in two forms: First, a certain volume which can be liberated as phosphene; second, a stable compound which will not give up its phosphorus by action of moisture from the air or by long standing. This first amount is constantly passing off more or less, as time goes on. The amount of phosphorus that can be liberated as phosphene can be determined quite easily, and was found to be between 30 and 80 percent of the total phosphorus. The following method was used and gave good results:

The finely ground sample is treated with 40 percent solution of caustic soda, and the hydrogen phosphide absorbed by bromine water. The phosphorus is determined in the bromine water, and also in the residue. The hydrogen phosphide will be carried over to the bromine water by the large volume of hydrogen gas liberated, which will be about 150 liters of hydrogen for 100 grams of 85 percent silicon. Arsene will also be absorbed in the bromine water and can also be determined.

Sulphur.

The solution of the ferro-silicon sample for this determination is accomplished the same as for phosphorus determination until after the first evaporation. The residue is taken up with water and washed into an acid. To the beaker is added 30 c.c. of concentrated hydrochloric acid; evaporate several times to dryness with other additions of acid. Then the solution is filtered and the residue burned from the paper. The residue is then fused with carbonate and leached out in the same way as for phosphorus. The liquor is filtered into the original filtrate. The filter is rejected and the filtrate precipitated by barium chloride. The determination until the sulphur is precipitated will take about 1.5 hours. If the solution is centrifuged the sulphur will be precipitated in twenty minutes completely.

Iron.

The chief trouble, and the place where the most time is lost in this determination, is freeing the solution of nitric acid, which on the other hand seems necessary to obtain solution of the

sample. This drawback was overcome, after considerable experimenting, by the use of hydrogen peroxide, 30 percent.

The following was the method worked out for this element:

Half a gram of finely ground sample is placed in a platinum dish and covered with 20 c.c. of hydrogen peroxide (30 percent). Hydrofluoric acid is added drop by drop. The dish must be kept covered with a watch glass, as the fine spray will carry off some iron if it is allowed to escape. When all is dissolved, the liquid is evaporated to dryness after the addition of 6 c.c. of hydrochloric acid. Then 30 c.c. of hydrochloric acid (1:1) is added, and the chlorides taken up with hot water, transferred to an Erlenmeyer flask, and titrated in the usual way with potassium bichromate, after reduction by stannous chloride.

In samples of ferro-silicon containing no titanium, the peroxide acid solution can be evaporated with sulphuric acid to dryness, then taken up and reduced with zinc and titrated with potassium permanganate. Ferro-silicon made from ores and cinders usually contains titanium, so the bichromate method is suggested for general practice.

Titanium.

This element has been rather neglected as far as methods are concerned that can be handled by the average operator. The methods are long, and so many elements interfere more or less that varying results are usually obtained unless under the hands of a very careful operator. The following method has been worked out for its determination and has been found to meet the demand admirably.

Half a gram of finely ground sample is placed into a platinum dish and 10 c.c. of concentrated nitric acid added, also dilute sulphuric acid (1:1) in amounts as follows: 6 c.c. for 25 percent; 3 c.c. for 50 percent; 2 c.c. for 75 percent; 1¾ c.c. for 85 percent ferro-silicon. Hydrofluoric acid is then added in drops until sample is decomposed. The solution is then evaporated to dryness and fumed until all the sulphur trioxide fumes pass off. Then the residue is taken up with 10 c.c. of hydrochloric acid (1:1) and filtered off.

The filtrate is reduced by zinc until all the iron is reduced, and then again 15 or 20 minutes longer with fresh zinc. The titanium

is only completely reduced to the titanous condition by this later treatment. Then quickly filter through glass wool and titrate with ferric alum solution, using KCNS as indicator.

The above method was used with great success on ferro-titanium containing 25 percent titanium, and also on silicon-titanium irons. When the percentage of titanium increases above a few percent it is necessary to make the reduction in a current of carbon dioxide.

Calcium and Magnesium.

Calcium can be determined by breaking up the sample as explained before, evaporate to nitrate dryness, take up with water and wash into a beaker. The hot solution in the beaker, after 40 c.c. of concentrated hydrochloric acid has been added, is made alkaline with ammonia water. The precipitated hydroxide is filtered off, and the calcium precipitated from the filtrate; the magnesium is precipitated from the filtrate from calcium determination.

Aluminium.

The aluminium is determined in conjunction with the rapid method for silicon by volatilizing the silicon tetrafluoride, and burning the residue of sulphates to oxides. The oxide of iron residue containing the aluminium was transferred to a platinum crucible and fused with sodium carbonate. The fusion while hot is run up on the sides of the crucible and cooled. The fusion is dissolved in hot water in a platinum basin, and boiled until all hard lumps have disappeared. The solution is filtered and the filter washed thoroughly with hot water. The aluminium will be found in the filtrate as sodium aluminate. Silica will also be found, if not properly driven off. Many tests have shown no practical amount.

The solution is carefully made acid with hydrochloric acid and boiled. Then the alumina is precipitated by ammonia, filtered and burned to alumina. At this point it is well to say that in the many samples examined no phosphoric acid was found in the alumina precipitate; it was eliminated in the first stages of the process. This method also gives the aluminium free from titanium. The alumina obtained is as white as snow, which is hard to obtain by any other method, in such a rapid way.

Barium.

This element will very easily pass off as a fluoride and be lost, while the sample is being dissolved. This element under these conditions has the property of distilling more readily than either silicon or titanium.

By adding to the dry ferro-silicon sample 15 c.c. of sulphuric acid (1:3) and then the nitric acid as before, and then the hydrofluoric acid in drops, all the barium is kept from distilling. The acid iron solution is then evaporated to SO_3 fumes and cooled. Dilute with water and boil until all is dissolved except a residue containing any barium present. Then the solution is filtered and the residue, with paper, burned in a platinum crucible and fused with sodium carbonate. The fusion is then extracted with water and filtered from the barium carbonate. The filter is treated with dilute hydrochloric acid, and the barium precipitated in the filtrate by sulphuric acid, and weighed as barium sulphate.

Silicon.

The method for the silicon determination is generally understood, except for a few improvements.

Ferro-silicon up to 25 percent can be decomposed by carbonate fusion in a platinum crucible, if carefully handled, without any danger; but above these percentages the fusion is very injurious to platinum and should never be tried. Ferro-silicon above 25 percent can be broken up with sodium peroxide in an iron crucible. The iron crucible is much cheaper and lasts fully as long and sometimes longer than a nickel crucible.

The trouble found by all chemists in evaporating sodium chloride solutions to dryness to dehydrate silica is the crawling of the solution. This can be overcome partially in different ways, but the best way is to eliminate the cause of the trouble—the sodium radical. Potassium was substituted for this and it was found to completely eliminate the trouble.

The trouble then was to obtain potassium peroxide. This was replaced by potassium hydrate, which broke up the alloy completely. The silicon from this point was determined the same as in a carbonate. For low-grade silicons, 10, 15, 25 percent, potassium carbonate was used.

An approximate method, accurate within 0.5 percent, is the evolution of the silicon as tetrafluoride, and burning the iron sulphate to Fe_2O_3, which will readily happen when sulphates are ignited, but when nitrates are ignited a mixture of oxides is obtained.

A factor should be used to counteract the difference in weight of aluminium and iron.

Sampling.

Chemists cannot be too careful in sampling ferro-silicon, as the segregation is enormous in the high grades. The silicon seems to separate from the iron silicides and goes to the top of the casts when cooling, after being tapped from the furnace.

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DISCUSSION.

HENRY R. POWER[1]: Our laboratory has found that the substitution for an iron for a nickel crucible in the fusion method for determining silicon is not feasible, even for economic reasons, nor does it solve the problem of a "blank" run with each determination of silicon. Nickel ware of these war times is not only scarce but of very poor quality as compared with that of two years ago. Formerly we made a dozen or more fusions in a nickel crucible before "the bottom dropped out." Nowadays we can make about three before the crucible is scrapped. A sheet-iron crucible costs about 30 cents, but it permits of only one fusion with peroxide. A nickel crucible costs 90 cents and will last for three fusions. Thus we see that the cost for each kind of ware is about the same.

We use a mix of 5 grams of sodium peroxide and 6 grams of sodium carbonate for a half-gram sample of 10 percent ferro-

[1] Chemist, Carborundum Co., Niagara Falls.

silicon or 90 percent silicon metal. This amount of alkaline mix yields the equivalent of about 0.2 percent silicon when simply dissolved in acid and evaporated for silica, but when fused in a nickel crucible or an iron crucible it is 1.5 percent.

The use of potassium or sodium carbonate for opening-up a sample of ferro-silicon, as recommended in Mr. Anger's paper, is not practical in the case of a 15 percent ferro-silicon, as the decomposition is far from complete. We doubt whether potassium hydroxide can be substituted for the peroxide.

The expensive change from sodium salts to potassium salts to prevent creeping over the sides of the casserole when dehydrating silica is hardly justified. It has been our experience that if the level of solution before starting the evaporation is kept beneath one-half an inch below the top rim, and if the rim of the dish is rinsed off and wiped dry, evaporation on a hot plate will rarely result in creeping over the edges.

EARL M. ANGER (*Communicated*): It is very hard to tell how Mr. Power makes his fusions, but from the data given, three fusions for a nickel crucible and one for an iron crucible, it is quite apparent that the crucible situation must pay the dealer well who supplies the crucibles; perhaps it would do well to say that I have seen as many as 60 fusions of all grades of ferro-silicon taken from one wrought-iron crucible as against ten fusions in the nickel crucible. If Mr. Power would use a spark coil containing a small condenser and ignite with nickel wires, he may get as high as 300 determinations from one iron crucible or about a quarter as many from a nickel crucible. The highest number of fusions made in one iron crucible that I have known, made with spark coil and well regulated mixture, was I believe 407 or 409. With the correct mixture the crucible can even be placed in water and then ignited. It is impossible to say how many hundred could be made in this way.

Potassium or sodium carbonate breaks up completely ferro-silicons up to 25 percent Si, when ground fine. Many samples of silicon pig 10 to 13 percent Si, and also 15 percent ferro-silicon containing about 1.0 percent C have been completely decomposed with sodium carbonate, but as the silicon rises, danger develops

of corroding the platinum crucibles. Ferro-silicon containing 25 percent Si should be decomposed by sodium peroxide. I have had no trouble at all in decomposing 10 to 15 percent ferro-silicons with carbonates.

In regard to the potassium hydroxide reaction on ferro-silicons, it would be well for Mr. Power to add a "small quantity" of finely ground 75 or 85 percent ferro-silicon to molten hydroxide and see if it cannot be substituted for peroxide.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918. President Fink in the Chair.

THE VOM BAUR ARC FURNACE.[1]

By C. H. vom Baur.[2]

Abstract.

Description of a new design of electric furnace particularly designed for melting ferro-manganese or ferro-silicon, or melting down cold charges for steel castings. Three electrodes in line are connected with a 2-phase, 3-wire system, giving advantages in melting down the charge which are described in the paper. Particular stress is placed on the natural contour of the furnace interior, minimizing heat losses and destruction of the walls. Details of construction and operation are given.—[J. W. R.]

This furnace design was created after observing many different electric furnaces in operation, and operating many of them also. There are several defects of previous arc furnaces of the simpler polyphase, solid bottom type, which this new design (U. S. Patent No. 1,252,633) endeavors to remedy. (Only polyphase furnaces are compared, and then not those which have the complication of pierced or conducting bottoms.)

Briefly, this polyphase, solid-bottom, arc furnace has a 2-phase, 3-wire connection, with the three electrodes in a straight line, the center electrode carrying the heavier current, all contained in an oval-shaped hearth, which has an equal heat gradient at the slag line. Fig. 1 shows the electrical connections, and Fig. 2 a plan view of the relative positions of the electrodes and the slag line. Figs. 3, 4, and 5, are respectively the plan view, the end view, and the rear view of the furnace.

As the design follows easy, natural lines, furnaces as small as

[1] Manuscript received April 2, 1918.

[2] Engineer, 233 Broadway, New York.

½-ton and as large as 15 tons are now being made. In the larger furnaces, the rolling features of the Wellman type have been adopted, whereas with some of the smallest the tilting is accomplished, keeping the spout almost stationary, by having the fulcrum directly beneath it, which facilitates pouring into small hand-ladles.

The advantages of this shape of hearth, together with the 2-phase, 3-wire connection, and the electrodes in a straight line, are many and far reaching. For instance: when burning in a basic bottom, as the electrodes are in a straight line, the heat of the arcs can be transmitted to a scrap carbon electrode lying horizontally on the bottom directly beneath all three vertical electrodes, and thence to the basic layer being sintered. Whereas, with arc furnaces having their three electrodes placed in triangular

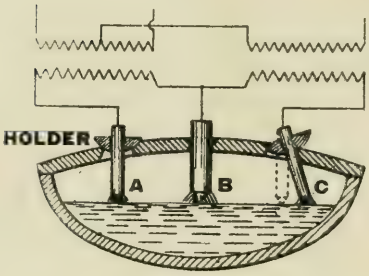


Fig. 1.

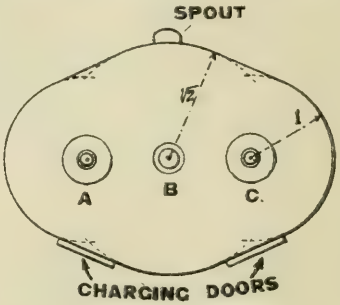


Fig. 2.

form, or those using four electrodes in a rectangular form, two carbon blocks at least are necessary in order to bring the electric arcs into play for sintering in the bottom.

When the furnace is ready for operation and cold metal is to be melted and treated, the charge thrown into the furnace piles itself into a natural heap with its apex directly underneath the central electrode, which carries 41 percent more heat into the furnace than either of the two end electrodes, underneath the latter, while there is a smaller amount of metal. This then is a natural condition all around, and greatly facilitates the melting process. Should it, however, be desired to melt this metal heap even faster, or more efficiently, due to the elevation of the scrap pile to be melted, then the end electrodes can be tilted toward the apex of the cold charge by a suitable mechanism shown plainly

in Fig. 5, namely, large screws and wheels, shown near the top of the electrode standards. This brings the end electrodes' arcs also on or nearer the top of the metal to be melted, in the form of three independent arcs, or, if its central one is buried partly in the charge, the other two arcs will quickly aid to melt down this pile, with the so-called "melting from the bottom" method. The ease with which this is accomplished is apparent.

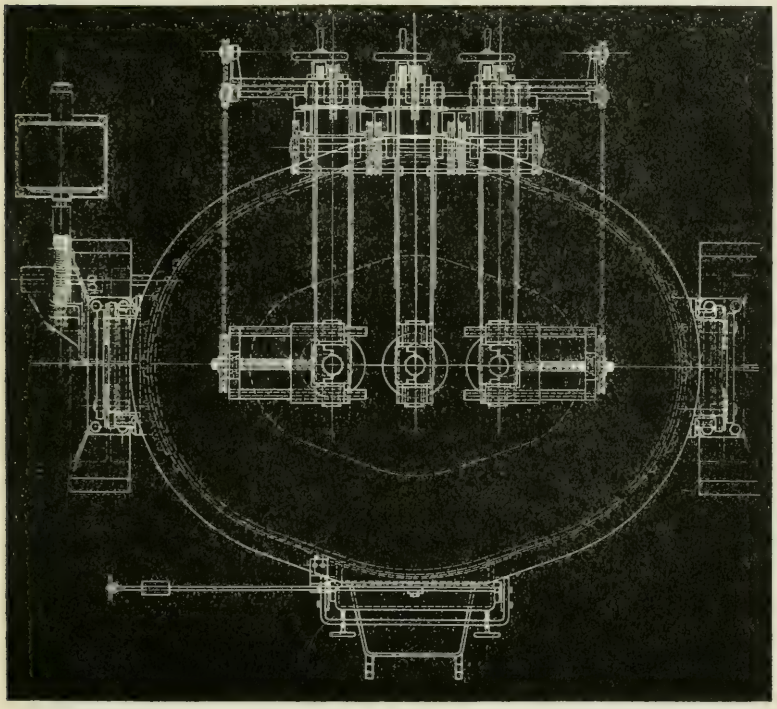


FIG. 3.

It will hardly ever be necessary to search for cold corners with this design. However, should metal freeze on the bottom or sides due to partially pouring and recharging some cold metal, the end electrodes can be shifted to ferret out some offending spot, as shown in Fig. 1. In the normal operation, should the end electrodes be tilted toward the top of the heap of steel, etc., in the beginning, they are moved out gradually to their vertical position

as the melting proceeds. From then on the heat at the slag line is the same, and also all over the entire side walls.

The importance of this cannot be over-estimated, for with this

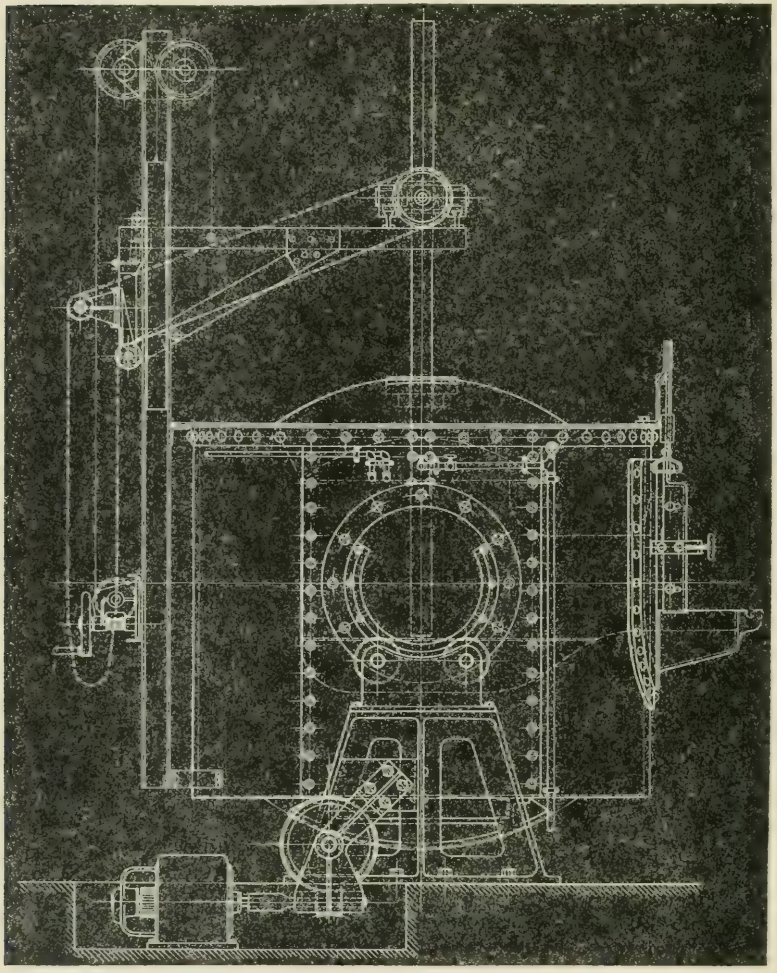


Fig. 4.

design the side walls wear out equally, and there is consequently no occasion for premature shut-down due to some places at the side walls wearing out faster than others. It is, of course, to be

remembered that there is no danger of melting down the side walls or roof during the melting-down period, no matter what the position of the electrodes may be with this furnace, due to the very great capacity for absorbing heat which unmelted iron and steel possess.

When the furnace charge is once melted, the excess heat is carried away through walls and roof, if not too thick. If at this time the walls are not subjected to a uniform temperature, they burn away at the hotter portions until they take on a curve exactly in harmony with the average excess heat which they have had to endure. This furnace design, starting out with a theoretically and practically correct contour of side walls, does not suffer from these ills which other polyphase furnaces are heir to. Another advantage of this shaped hearth is that for a given capacity the bath surface is larger, hence has a greater slag area; and as the rate of refining steel depends not only on the temperature at the point of contact between the hot charge and the slag and its composition, but also on the amount of slag in contact with the metal, it is evident that this additional area of bath surface is of advantage when refining. The circulation of the molten metal should be ample, considering the greater heat directly beneath the center electrode, compared to that directly beneath either of the two other electrodes. The efficiency of the furnace, especially for hot charges, should be high.

The electrical connections are the simplest possible, as shown by Fig. 1, except for a variable-volt choke-coil in the primary circuit of the transformers.

The flexible cables coming to this furnace, necessary on account of the tilting action, connect to the electrode cooling clamps direct, and hang from bus-bars above the furnace and slightly to the rear. Thus all heavy copper near the furnace shell, or between or near the electrode standards, is avoided. Thus the high power factor is not affected, neither are the phases nor the arcs distorted.

The reason some electric furnace shells warp or bulge in some places is on account of the unequal heat distribution, not at the roof, but at the side walls. Since ordinary expansion of the brick work, which expands with heat, is anticipated and provided for in this furnace design, as shown in Fig. 3, the furnace should keep its shape better than others.

The electrodes can be regulated by automatic means or by hand. The phase voltage is usually 120 for melting down, and may be 90 or even 60 for finishing, with reduced power. Voltage taps on the transformers are 120, 105, 90, and the primary choke-

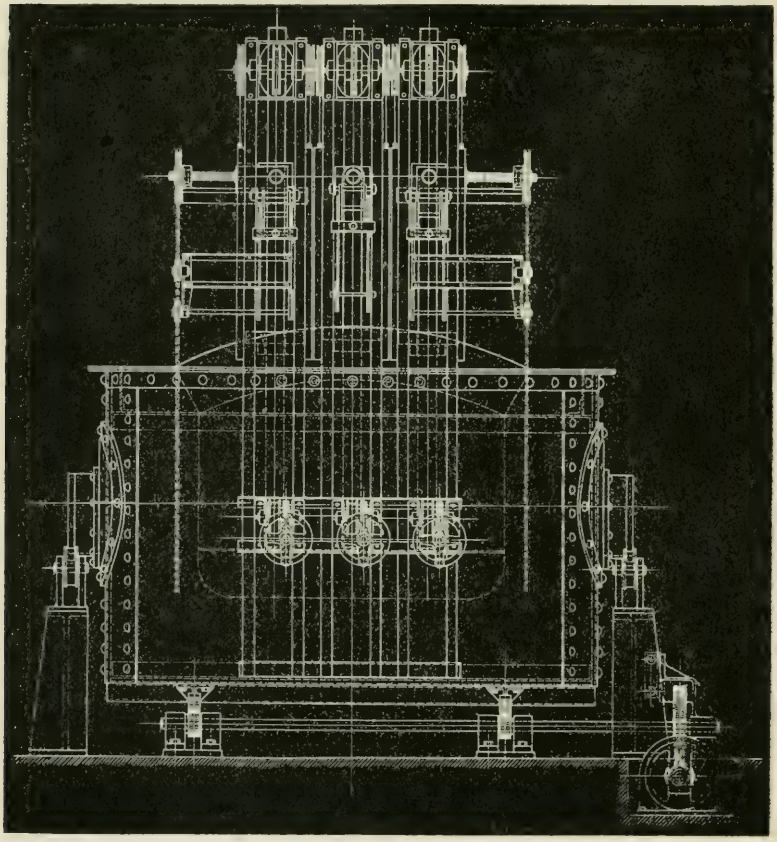


FIG. 5.

coils give an additional variation of 10, 20 or 30 volts from either of these points downward.

Considering the experience gained recently with furnaces melting ferro-manganese and ferro-silicon, this furnace design readily adapts itself for these purposes when fed with 1500 kilowatt transformers.

Considering the very extended use of electric furnaces in the iron and steel industry, and the new fields constantly opening to them, such as making low phosphorus pig iron from steel turnings, or high-grade grey-iron castings, low in sulphur, from cast-iron borings, etc., it seems that the ever-increasing field of application is large enough to admit of still another electric furnace, such as this one, making its bow to the public.

DISCUSSION.

H. E. WHITE[1]: It seems to me that a good many claims are made for this type of furnace. Is there any data available to substantiate the claims that are made?

C. G. FINK[2]: I believe I understood Mr. Vom Baur to say that he has two or three furnaces in successful operation.

J. W. RICHARDS[3]: A furnace like this which operates successfully would certainly be of great interest to the Birmingham district, because at the present time an electric furnace for melting ferro-manganese for use in steel is being used here in the Ensley plant, and, I understood today, with a saving of something like 15 percent of the manganese. This saving is a considerable item in these days of shortage of manganese, so that if this furnace is as good as Mr. Vom Baur says, it certainly has very great interest to all steel workers in this and other parts of the country. Mr. Vom Baur also speaks of the manufacture of low-phosphorus pig iron from steel turnings. The Society had a paper on that subject at our last meeting, by Mr. Turnbull, showing it was being done successfully in Canada, and there is probably a similar condition in this district, caused by the war. Low-phosphorus pig iron can be thus manufactured in the electric furnace from steel turnings at a commercial profit, at the present time, so that this furnace and its capabilities should certainly appeal to the steel makers of Alabama.

[1] Asst. in Res. Dept., The Norton Co., Niagara Falls, N. Y.
[2] Head of Laboratories, Chile Exploration Co., New York City.
[3] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.

C. H. Vom Baur (*Communicated*): Answering Mr. H. E. White's question of the claims made for this furnace, they have been met only for the operation of this type of furnace, excepting that with the larger size of furnace, that is to say, 3, 6, and 15-ton size, it has been found unnecessary to have the end electrodes adjustable so that their angle towards the bath and each other can be changed.

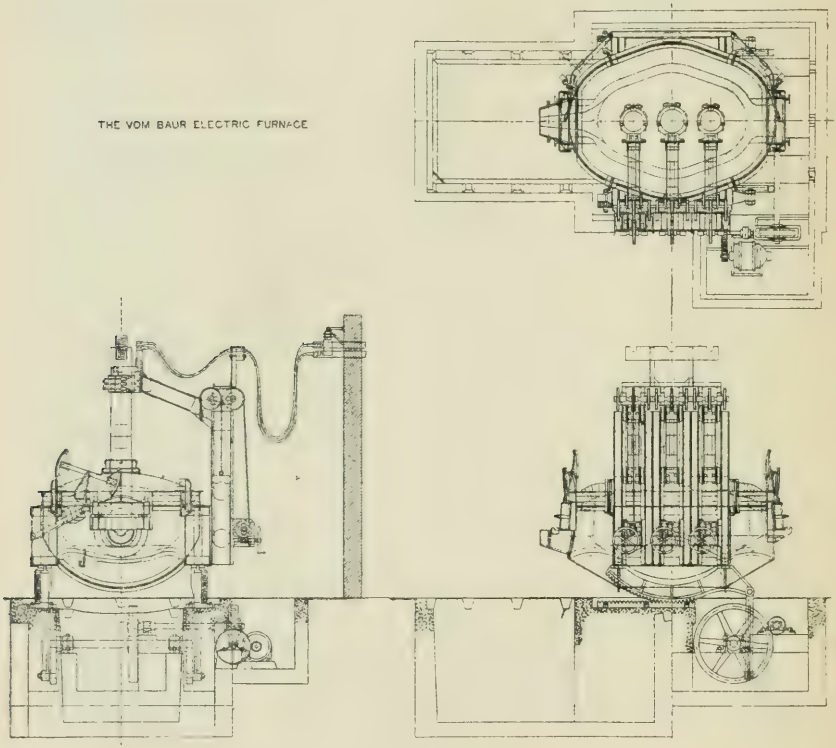


Fig. 6.

The uniform heating at the slag line and at the side walls is very evident, and the fact of not having any one place where the side walls wear out sooner than another has been found a great advantage. The efficiency has been found to be higher than expected, in the 6-ton design, which has only two doors, one at either end of the furnace (see Fig. 6), owing to the fact that

most of the electrical heat is developed in the furnace at its center, the point farthest away from the doors.

This feature is also of value when the metal is finally melted, as the electrode carrying 41 percent more heat to the furnace than either of the other two, is over the deepest portion of the bath. Owing to the dearth of graphite electrodes today, this furnace is also designed to operate with the larger diameter of carbon electrodes, and these are shown in Fig. 6.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918, President Fink in the Chair.

THE BOOTH-HALL ELECTRIC FURNACE.[1]

By W. K. Booth.[2]

Abstract.

A description of a newly-designed electric steel furnace of the vertical-arc type with conducting hearth, having two electrodes and an auxiliary electrode, and adapted to give a balanced load on a three-phase circuit, but also built for two- or single-phase circuits. It is particularly intended for melting down cold charges for steel-casting foundries.—[J. W. R.]

The principal difference between the various makes of electric furnaces is the method in which the power is introduced in the furnace. The general metallurgical operations of practically all electric arc furnaces are the same. The method of power regulation and bringing the power to the furnace frequently means greater or less cost in furnace operation and governs, to a considerable extent, the manner in which the furnace lining may be put in and consequently the refractory cost and the loss of time due to furnace shut-downs.

Electric arc furnaces may be broadly divided into two classes—

1. Vertical Arc Furnaces.
   (*a*) Conducting Hearth.
   (*b*) Non-conducting Hearth.
2. Horizontal Arc Furnaces.

It is not the purpose, here, to enter into a discussion of the merits of the various types of arc furnaces, but more particularly to describe a new type of electric furnace, which has been de-

[1] Manuscript received March 29, 1918.
[2] General Manager, Midland Electric Steel Co., Terre Haute, Ind.

veloped during the last year and which is known as the Booth-Hall Electric Furnace.

The Booth-Hall electric furnace comes under Class 1-*a* above, and is illustrated diagrammatically in sketches Figs. 1 to 4, and in the photographs from operating furnaces.

Fig. 1 is a longitudinal section of the two-phase electric furnace with the auxiliary electrode resting upon the charge and arcs

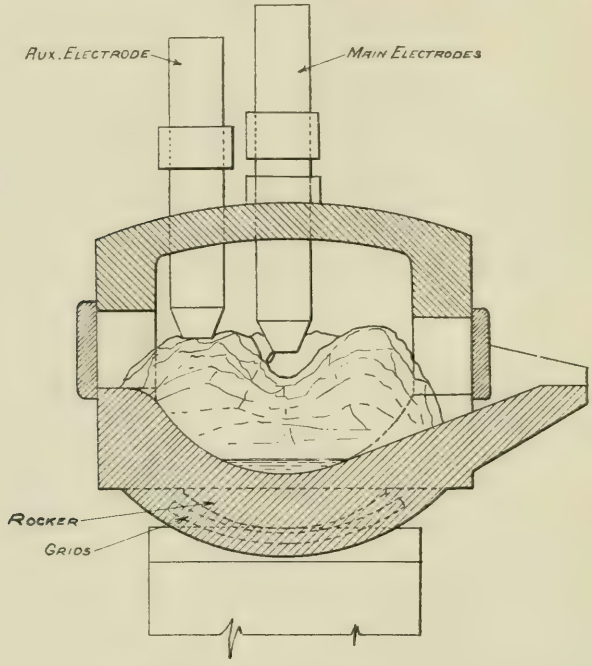


FIG. 1. Longitudinal Section of Booth-Hall Two-Phase Furnace.

drawn between the main electrodes and the charge. A pool of metal is shown forming on the hearth of the furnace.

Fig. 2 is a diagram of a transverse section of the two-phase electric furnace, showing the crossing action of the current in the bath and the grids embedded in the hearth.

Fig. 3 is a diagrammatic representation of the electrical connections for the two-phase electric furnace employing two single phase, Scott-connected, transformers. This diagram shows the connections from the transformer terminals to the main electrodes

and to the auxiliary electrode and grids. A two-phase electric furnace so connected gives a balanced load on a three-phase power service. The auxiliary electrode is shown in black.

Fig. 4 shows diagrammatically the arrangement of main and auxiliary electrodes in single-, two-, and three-phase Booth-Hall furnaces. The auxiliary electrodes are shown in black.

The furnace is built either single-, two-, or three-phase to suit

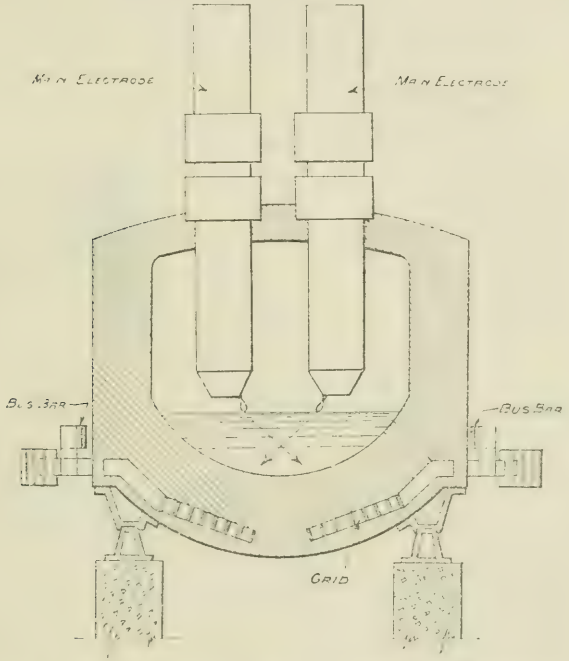


Fig. 2. Transverse Section of Booth-Hall Two-Phase Furnace.

the conditions at the place of installation, the general principle being a furnace having a solid hearth which becomes conductive of electricity when hot, and the use of an auxiliary electrode which acts as a return for the electric current until the hearth becomes heated and conductive.

In starting furnace operation on a cold charge the auxiliary electrode is lowered until it rests on top of the charge and the arc is then drawn between the charge and the main electrodes or electrode, as the case may be, the auxiliary acting as a return for

the main electrode or electrodes. The auxiliary is so arranged that it presses with its entire weight on top of the charge and consequently no arc can form underneath the auxiliary; experience has demonstrated that no arc does form. The auxiliary is connected in parallel with the conducting hearth, and when the main electrodes or electrode have melted enough metal to form a pool on the bottom the hearth becomes conductive and the auxiliary is withdrawn from contact with the charge. In a cold furnace the auxiliary is in operation from thirty to forty-five minutes, and in

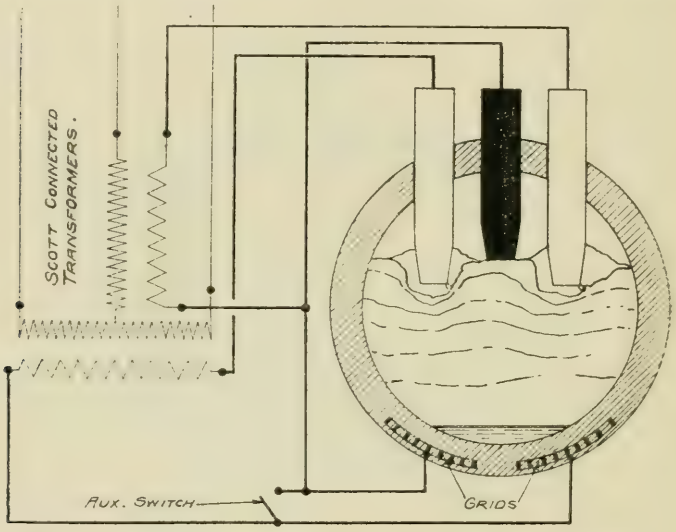


FIG. 3. Electrical Connections of Booth-Hall Two-Phase Furnace.

a furnace which is hot less than fifteen minutes; that is, only long enough to assure a positive start of the furnace and a balanced load on the power company's line.

Furnaces from one-half to six tons holding capacity are generally built for two-phase operation, taking power from three-phase service by means of Scott-connected transformers, as shown diagrammatically in Fig. 3. In the hearth of the Booth-Hall two-phase electric furnace two sets of grids are embedded, which are electrically insulated from each other and are so related to the main electrodes that the current of the two phases cross in the bath, thus giving a maximum of circulation of the molten metal and

causing, in conjunction with the effect of the bottom heating, a very thorough mixing of the metal in the bath. This action can readily be observed in looking into the furnace after the charge has entirely melted. The conducting grids are placed as far as possible from the heated interior of the furnace, and experience has shown that they never become overheated or require special cooling. The grids are so constructed as to handle large currents, furnishing large areas of contact with the material of the conducting bottom, and preventing local heating due to contact resistance.

By the use of the auxiliary electrode a positive start of the furnace is guaranteed, and there is no possibility of failure to secure contact. Each main electrode is independent of the other,

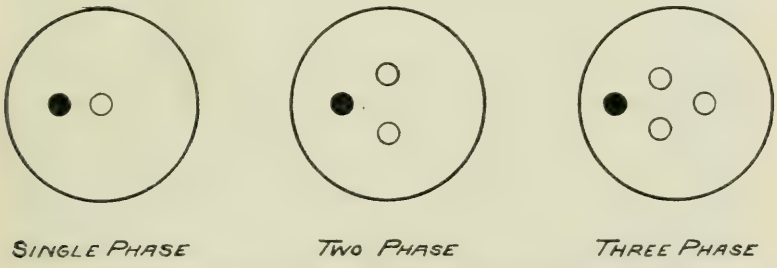


FIG. 4. Diagrammatic Representation of Electrode Arrangement.

as there are no arcs in series, and consequently the regulation of the furnace is very simple, giving a balanced polyphase load on the power service lines. As with the two-phase connection there are only two electrodes to regulate, this offers the minimum number of electrodes for a balanced polyphase load, and the smaller the number of electrodes requiring regulation the smoother becomes the furnace operation.

The hearth is either acid or basic, as desired, and in each case is at least 24 inches (60 cm.) in thickness, being sintered in place layer by layer and forming a monolithic mass. By using the main electrodes in conjunction with the auxiliary, the materials of the hearth are sintered together in thin layers similar to open-hearth practice, thus forming a very durable bottom and making the danger of run-outs a minimum. The furnace hearth is, conse-

quently solid, with no water cooling of any kind. With the basic hearth, dead burned dolomite is used to maintain the slag line; in the acid furnace, ground ganister is used for the same purpose. The conducting hearth gives a uniform bottom heating of the

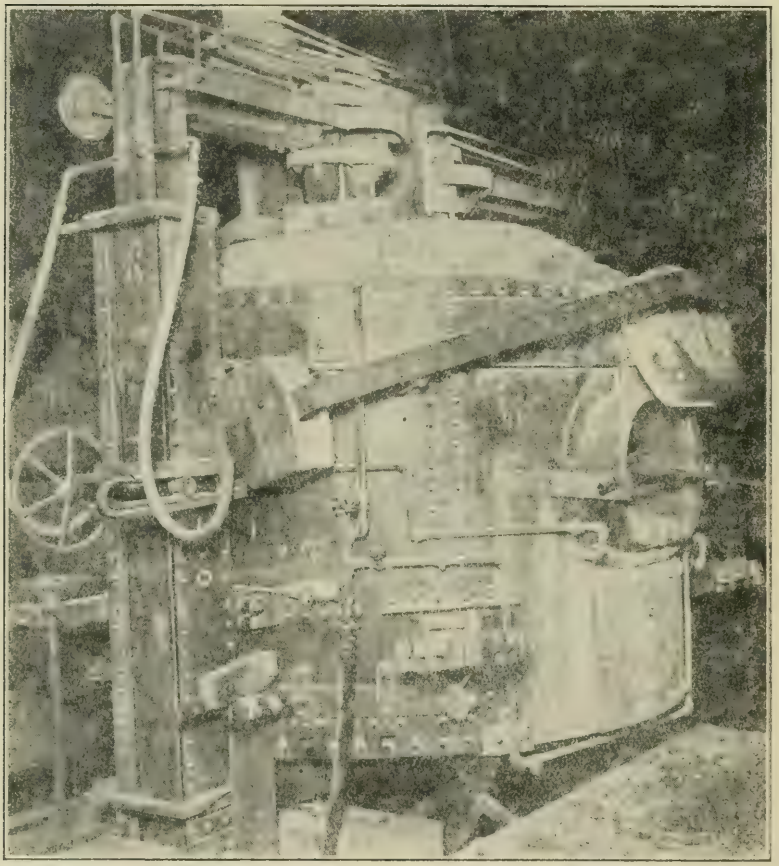


FIG. 5. Rear View of Four-Ton Booth-Hall Two-Phase Furnace.

entire bath, prevents sculls, and makes speedier and more thorough distribution of the heavier alloys, which tend to sink to the bottom of the bath. The effect of this bottom heating is considerable, and has been accurately measured on Booth-Hall furnaces in continuous operation.

With the two-phase electric furnace a minimum of electrode consumption is secured, due to the fact that a minimum number of electrodes for a balanced polyphase load is used. This means less electrodes to handle, less electrode breakage, and less surface

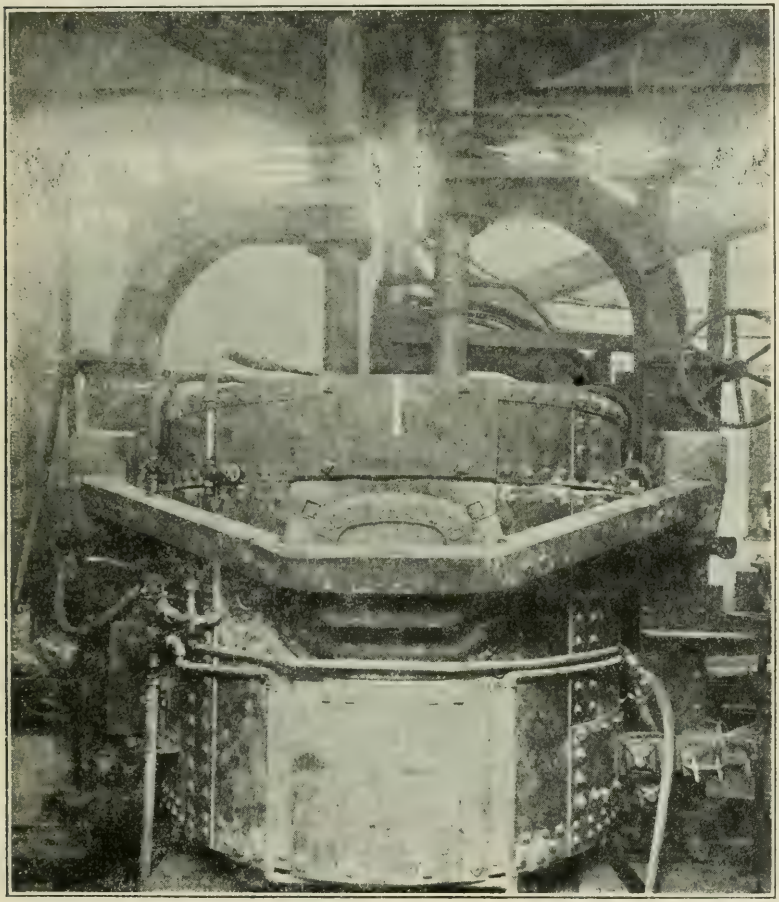


Fig. 6. Rear View of One and One-Half Ton Booth-Hall Furnace.

burning. The loss on the auxiliary electrode is small, because it is in operation for such a comparatively short time. The electrode jaws are made so that the electrodes can be gripped or released by turning a handwheel or lever at the side of the furnace and

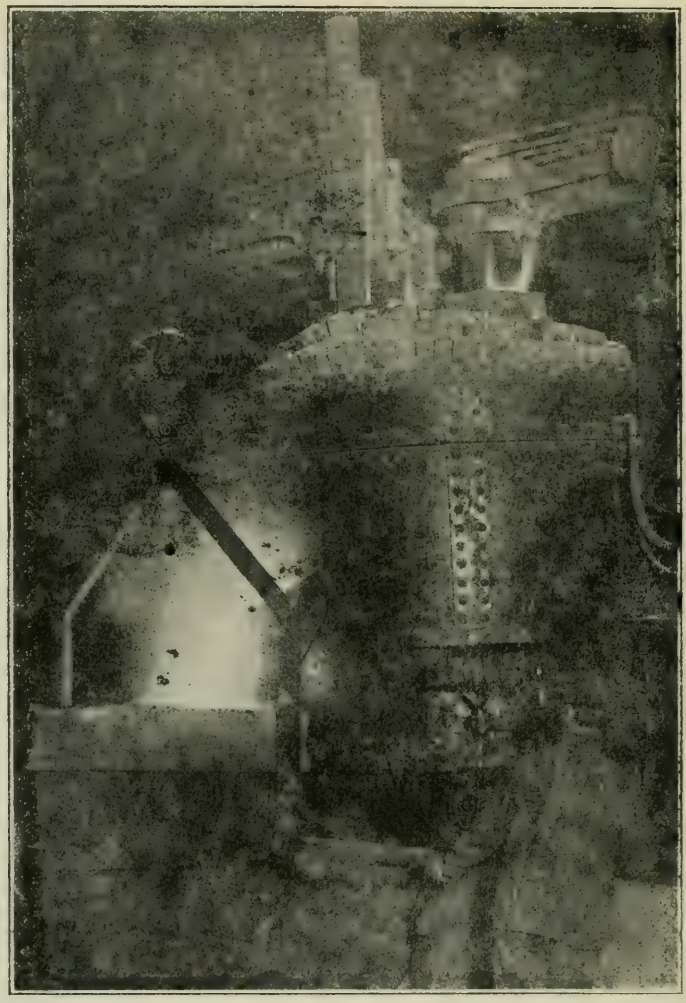


FIG. 7. Four-Ton Furnace Pouring. As only small electrodes were available, three were used clamped together.

it is not, therefore, necessary for the melter to climb on top of his furnace when changing the grip on the electrodes. The electrode jaws are arranged in segments so as to take up and adjust themselves to the inaccuracies in the surface of the electrodes.

A roomy charging door of special construction is provided in

the rear of the furnace and another door provided in front over the tap. This construction is very similar to the open hearth, and permits a battery of furnaces to be arranged side by side and a charging machine to serve them all. The furnace tilts or rocks backward as well as forward and slagging operations can be handled either from the rear or front as desired. The door is

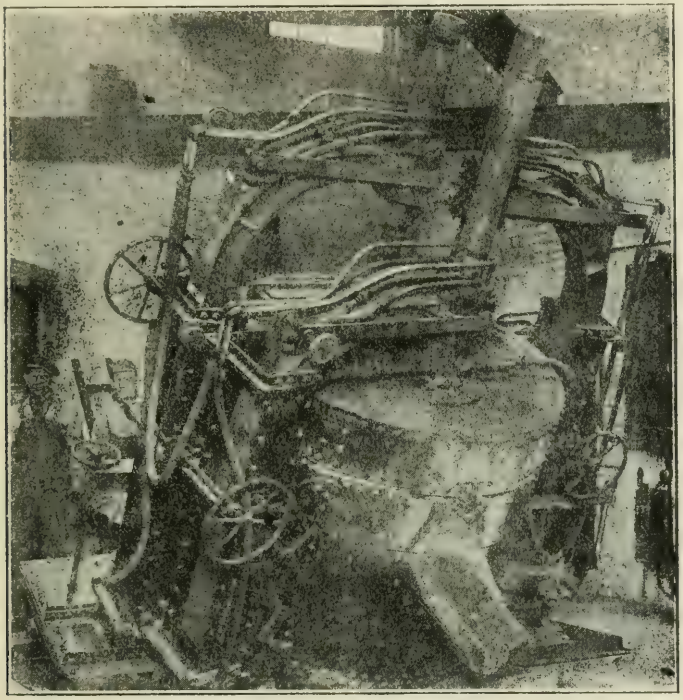


FIG. 8. One and One-Half Ton Furnace in Pouring Position.

shown in the various photographs. It is designed so that it comes flush against the door frame, sealing the opening, and cannot swing open of its own accord. This prevents air getting into the furnace and also prevents excessive losses of heat through the door. The door can be opened anywhere from a few inches to full open, when inspecting the bath, taking tests or pushing scrap from the sides of the furnace into the bath, thus protecting the melter from the heat of the furnace and preventing great radiation loss. Any

warping of the door or frame does not affect the operation of the door or its sealing of the opening when closed.

The furnace is motor tilted, in all sizes, for pouring, but is arranged so that it can be tilted by hand, in emergency, if the motor fails to operate. The smaller sizes of furnace are built for hand operation only, if desired. All parts of the tilting mechanism, including gears and motors, are arranged so that they do not come beneath the furnace and, therefore, there is nothing under the furnace that can be injured in case of a run-out.

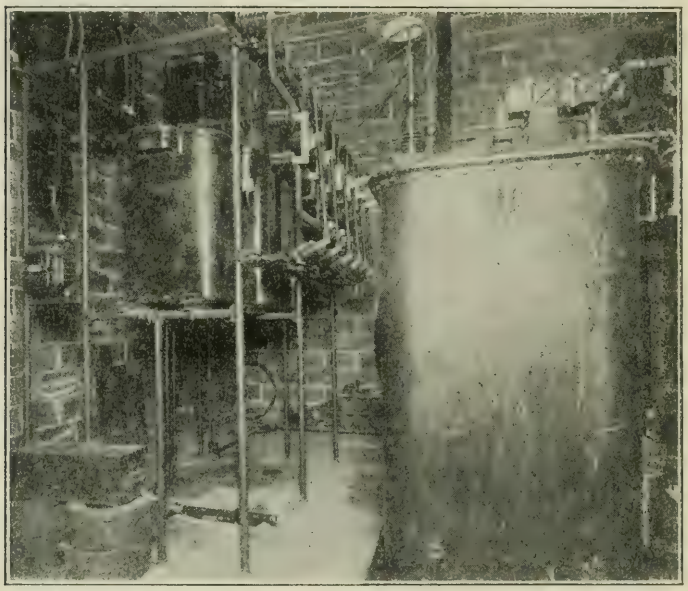


FIG. 9. Booth-Hall Electric Furnace Substation.

The main electrodes are arranged for automatic regulation and also, in every case, that they can be regulated by hand in case the regulators or motors should require repair.

The importance of power control is universally recognized, especially when refining operations are carried on. In the Booth-Hall electric furnace the power input can be maintained at any point from one-fourth to full load by means of proper voltage reduction and control switches.

In making steel for the ordinary grade of steel castings, the

Booth-Hall electric furnace has operated with a power consumption as low as 446 kilowatt-hours per 2,000 pounds (906 kg.) of steel poured, but the average will run between 500 and 550 kilowatt-hours per net ton, for continuous operation. In one of the four-ton furnaces a considerable quantity of low phosphorus pig iron has been made, running under 0.035 percent in phosphorus and sulphur, also special steels requiring refining with two or more slags; the power consumption, of course, depending upon the degree of refining required.

DISCUSSION.

J. L. McK. YARDLEY[1]: I desire to point out one thing in connection with this furnace. The author devotes nearly his entire attention in this paper to his two-phase furnace, that is, he has a three-phase supply but his furnace is a two-phase furnace and he gets the necessary two-phase power by means of a Scott connection. Experience shows that such a connection usually results in a more expensive set of transformers than that required by straight three-phase to three-phase transformation. This is largely due to the fact that transformers for three-phase to three-phase transformation have become standardized and are built in large quantities, while on the other hand, transformers for three-phase to two-phase transformation have not been built in quantities, and usually require development expense which adds very considerably to the total cost.

MR. NORRIS: I would like to make the point that one of the striking features of this furnace is this new method of opening and closing the door, which is quite important. I should consider that there is a good deal of erosion and wear and tear on the furnace door, and you will note from the pictures shown on pages 252 and 253, that the author has a new method of practically capping over the door so that it can be held fairly tight no matter what the erosion of the refractory on the inside, and it is very easy to repair and keep in order in that way. I think it is a distinct departure from the ordinary method of construction, and I think that is one of the strong points of the furnace.

[1] General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

E. KILBURN SCOTT[2]: For a two-phase furnace, I think the auxiliary electrode would be useful, because when a bottom electrode is connected to the middle point of a two-phase supply there is very poor electrical connection until the furnace bottom has warmed up.

With a three-phase furnace there is not the same advantage in having an auxiliary electrode, because current flows through the bottom much more readily, due to the difference of potential to the third phase, under the hearth, being always the full amount.

When a furnace has a bottom electrode, the charge is heated up in two ways, first by the arcs formed between the top electrodes and the charge, and second, by the resistor effect of the hearth or lining below the charge.

To get the best effect from the resistor it is well to have the path through it, from the charge to the electrode, about the same at all points. That is to say, the electrode should be made to about the same contour as the hearth.

Sometimes one sees designs in which the electrode consists of flat strips of metal embedded in the bottom of furnace, and these naturally give a greater depth of resistor around the edge than in the center. In this case most of the current flows through the central portion of the lining, and this is liable to intensify erosion of any holes that may form. When a small hole is started, the metal pours into it and the distance between the bottom of it and the electrode being shorter than elsewhere in the lining, extra current flows and a pinch-effect is set up. This pinch-effect erodes the hole and it very soon enlarges, because the effect is cumulative. The deepening may become so rapid that metal gets through the bottom.

The success of any furnace depends to a considerable extent on the materials used for the lining and on the way they are built up. It is best to build in comparatively thin layers, and see that each layer is perfect before the next one is put on.

JOS. W. RICHARDS[3]: There is a figure given on page 257 which may be interesting from the standpoint of furnace efficiency. The furnace apparently runs with high thermal efficiency. The

[2] Electric Furnace Expert, New York City.
[3] Prof. of Metallurgy, Lehigh University, Bethlehem, Pa.

figures 500 to 550 kilowatts per net ton correspond to 70 to 75 percent thermal efficiency and the minimum figure given, 446 kw. hours would correspond to nearly 85 percent thermal efficiency; assuming 375 kw. hours as the minimum necessary to melt steel. If those figures are reliable they show a very high thermal efficiency for that furnace.

CARL HERING[4]: Is that assumption of the theoretically correct value safe? What authority have we for it?

J. W. RICHARDS: Experimentally taking the melted steel and dropping it into water, measuring how much heat energy is in it, and calculating how much net electric energy that is equal to.

CARL HERING: This involves the superheat; is this the same in both cases, and if not, is not the superheat a very important factor?

J. W. RICHARDS: The superheat was the same. The melted steel was taken from an electric furnace, granulated in water, and we then calculated how much electric energy was represented in the heat given up by the steel.

CARL HERING: When molten steel is dropped into water considerable steam is produced, and the latent heat of producing this steam does not appear in the calorimeter reading; it may be an important part of the whole. For this reason I suggested some time ago to make this test by pouring the molten steel into a mass of lead in a vessel which is suspended in the water of the calorimeter and then making the correction for the heat capacity of the lead after all three are at the same temperature. This theoretically correct figure is of great importance, and it seems to me that this test ought to be made.

MR. BITTING: I should like to ask whether members have had any experience in the use of this electric steel furnace in connection with ferro-alloys?

C. G. FINK[5]: May I ask what particular ferro-alloy you have reference to? Ferro-silicon?

MR. BITTING: Yes; the author speaks of ferro-silicon and ferro-manganese as being applicable to this type of furnace. I

[4] Consulting Electrical Engineer, Philadelphia, Pa.
[5] Head of Laboratories, Chile Exploration Co., New York City.

would like to ask whether any of the members have had experience in the use of a steel furnace of this type in the preparation of ferro-alloys of any kind?

C. G. Fink: Are there any present who are familiar with the Booth-Hall furnace? Personally I have not seen it in operation.

Mr. Bitting: I understand there is an experiment shortly to be made at Amesbury, Mass., on the making of ferro-silicon in this steel furnace; that is the only instance I have heard of, in which it is going to be tried out on this line.

W. K. Booth (*Communicated*): It has been our experience that the cost of the transformers for three-phase furnace installation of a given K.V.A. capacity, will be somewhat greater than for the same K.V.A. capacity two phase, in case the three-phase installation consists of three single-phase transformers. However, if the three-phase furnace installation consists of a single unit three-phase transformer, this type of installation is somewhat cheaper than using two single-phase transformers, Scott connected, for two-phase power. There is a disadvantage, however, in using a single unit for three-phase operation (although it is quite customary to do it at the present time), because if anything should happen to one phase of the three-phase transformer, the entire transformer would be out of commission, whereas in using three single-phase transformers, if anything happens to one of the transformers, it would still be possible to run the furnace at reduced capacity, using the other two.

The door which is used on the Booth-Hall furnace and mentioned by Mr. Norris, has indeed shown very excellent results, as we have not yet been required to replace a door frame on any of our furnaces, or the door castings themselves, and at all times we get a door which seals very tightly under the various conditions of furnace operation.

The discussion by Mr. Scott has many points that are not clear. As will be noted in the illustrations in my paper, the grids which are embedded in the lining on the bottom of the furnace are at all points approximately the same distance from the steel bath in the furnace. This means that the current distribution over the entire bottom of the furnace is very uniform, and there is no excessive local heating. Consequently we have never had any

difficulty in maintaining our hearth. In fact, up to the present time we have never had a runout through the bottom, and have never noticed the action mentioned by Mr. Scott in regard to a hole starting in the bottom and going down through it.

Regarding the power consumption of the Booth-Hall electric furnace, the records given were those made in regular commercial operation. Some time ago I had the opportunity to supervise some tests on the theoretical power required to melt structural steel and pour at a temperature of 1600° C., and the tests indicated that the amount of power required was about 350 kw. hours per net ton. The test was carried out in the same manner as explained by Prof. Richards, his figure being 375 kw. hours.

Regarding the use of electric steel furnaces for making ferro-silicon, the steel furnaces are not of the proper type to operate economically making this product. I have had some experience in making high-percentage ferro-silicon, but have always used an open-top type of electric smelting furnace; I do not believe it would be economical to use furnaces of the steel-melting type. There are certain other ferro-alloys which could be made in a steel melting furnace, but this remark does not apply to ferro-silicon.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Birmingham, Ala., May 3, 1918. President Fink in the Chair.

ELECTRIC STEEL CASTINGS.[1]

By R. F. Flinterman.[2]

Abstract.

Continuation of a report of foundry experience making electric steel castings, in which a considerable saving of power and quicker running of the furnaces, giving greater output, was attained by applying some principles brought out by a paper discussing the electrical connections of furnaces and the avoidance of skin effect in the conductors, read at a previous meeting of this Society. Very fine mechanical qualities in special alloy steels are shown as obtainable, exceeding by far the requirements of our army and navy specifications. [J. W. R.]

This same subject was treated by the writer in a paper at your Thirty-first General Meeting, held at Detroit in May, 1917.[3] It is my present intention to make comment on some of the ideas set forth in this earlier paper, and to report to you certain changes and improvements that we have been able to make.

In the paper, previously referred to, a process to which I gave the name of "Reversed Duplexing," was brought to the attention of the Society. Briefly, this process consisted of making steel in electric furnaces, say two or more, at least one of which was run with basic lining, and the rest of the furnaces were to be run with acid lining. The plan proposed was to use the basic furnace as a feeder for the acid-lined furnaces. The basic furnace would use lower-priced scrap, and refine same for sulphur and phosphorus, and the resultant dephosphorized and desulphurized steel would

[1] Manuscript received April 4, 1918.

[2] Michigan Steel Castings Company, Detroit.

[3] Trans. Am. Electrochemical Society, 1917, 31, 69.

be transferred to the acid furnace, which in the meantime had been melting steel scrap in the usual manner, and would receive the refined charge from the basic furnace after its own charge (that is the acid charge) had been completely melted. The furnaces would be of such size and their operation so timed that the total output of all the furnaces so run would be the same as though they had all been run independently.

The advantages set forth for this "Reversed Duplexing" were as follows:

1. The cost of at least a part of the raw material would be lower.

2. Basic furnace could be run at a comparatively low temperature during the refining period, and the life of roof and walls would be prolonged. The final temperature could be attained in the acid furnace, where necessary temperaure and fluidity can be attained without injury to the lining.

3. The final metal would be lower in sulphur and phosphorus, and the process properly carried out would cost less than metal produced by the acid process.

4. The final deoxidation would be carried out under an acid slag.

The great advantages obtained because of this final refining under an acid slag were pointed out in my earlier paper and need not be repeated here. The writer intimated therein that we might soon be in position to give the "Reversed Duplexing" a thorough trial. As yet we have not been able to do so, and it may be interesting to know why we have not done so. The main reason is that we have been able to increase our tonnage to such an extent with our present furnace equipment, that the addition of another furnace would not be economical.

In May we were producing about 42 tons per day, which is just about the rated capacity of a 6-ton furnace and a 3-ton Heroult operated together. Making five heats each per 24 hours would make a total of 45 tons for the two furnaces, and we might add that it took us a year or more to be able to attain this tonnage regularly. Now, however, we average close to 60 tons per day, and have actually made 64 tons per 24 hours and expect to attain an average of 70 tons.

These performances are due to two things: (1) A general improvement in our methods, and (2) some slight changes in our furnace construction.

As regards our own methods, we cut down the time necessary for all operations, simply because the entire furnace crews are much better acquainted with the apparatus they are working with. The installation of a bonus system has speeded up everybody. The melters and helpers are on a bonus tonnage system. The chargers (and by the way all charging is done by hand) are paid under a system which pays them a high wage if charging is done in a short time, and a much lower wage if charging consumes a longer time than necessary. We have also installed a new crane which serves the furnaces alone, so that no time is lost when the crane is needed at furnace. So much for our own methods.

As regards the change of furnace construction, we derived our inspiration from the paper presented by Mr. A. A. Meyer on "Electrical Characteristics of Electric Furnaces," which paper was also presented at the same General Meeting in Detroit in May, 1917.[4] I will quote one paragraph from this paper.

"Next, a few readings were taken of the voltage drop over the various portions of the bus leads to the electrodes and also of the drop across the arc itself. Starting at the transformer and passing over the bus toward the electrodes, the points selected are designated as points 7, 1, 4, 2, 3, 8 and 6 in Fig. 3. Oscillograms Nos. 120, 122 and 124, in Figs. 13, 14 and 15, were obtained. It was found that of the total voltage available at the transformers as high as 24 percent was lost as drop in the copper bus between the transformer and the electrodes, the balance being available at the arc. This seems like a large bus drop and is due not so much to the copper resistance as to the reactance of the bus circuit. To determine in what portion of the bus the greatest drop occurred, measurements were taken between points 1 and 2, in Fig. 3, and compared with those between 2 and 3, and it was found that the drop per c.m. foot in the solid bus was over three times as great as in the flexible leads. Now, on account of the large cross-section of the bus to handle the large currents, skin effect may be a big factor in reducing the conductivity of the present bus, but it is believed that the induction of the neighboring steel work is largely

[4] Trans. Am. Electrochemical Society, 1917, 31, 97.

responsible for the greater drop in the bus bars. On account of the necessary steel work giving support to the busses and the electrodes and its close proximity and unequal exposure to the different phases, considerable induction is introduced which cannot be easily avoided."

Further, under his conclusions, Mr. Meyer writes as follows:

"Attention was called in this paper to the large voltage drop in the secondary busses going to the electrodes. It was found that about 24 percent of the available voltage at the transformer was lost as drop in the short bus between the transformer and electrodes. This was unquestionably due not to resistance, but to reactance which was introduced in the circuit by the neighboring steel structure of the furnace. Tests along various sections on this bus showed that the drop per c.m.-foot in the bus going through the steel structure, and with a current density of about 1.3 amp. per 1,000 c.m. (0.05 sq. cm.) was over three times that in the flexible bus leads more remote from the steel work and where the current density was about 1.7 amp. per 1,000 c.m. (0.05 sq. cm.). (See oscillogram No. 120, of Fig. 13). The desirability of such reactance is a matter somewhat in dispute. On the one hand, the value of such reactance is claimed in its effort to cut down or limit sudden rushes of large currents. It should tend to smooth out the sharp peaks. However, it does not appear to have such great effect in the oscillograms of Figs. 11 and 12. On the other hand, reactance in such a place is detrimental to the voltage regulation and causes a big reduction in the voltage available at the arc. It is of course primarily due to the bus bars passing through or in close proximity to the steelwork. Its magnitude cannot be easily evaluated because of so many unknown factors, and consequently little attention is sometimes paid to it in designing furnace installations. In view of its usually unknown value and the heavy currents to be dealt with in furnace work, it would seem more desirable to reduce it to a minimum and figure on a more definitely known inherent reactance to be incorporated in the power transformers. Closed magnetic circuits around or near any of the electrode circuits are objectionable for various reasons and should be avoided as much as possible."

You are familiar with the old method of bus-construction on the Heroult furnace. The 6-ton furnace has eight solid bus bars

¼" x 6" (0.6 x 15 cm.) solid copper 7 ft. (2.1 m.) long, for each phase, placed triangularly with 20 inches (50 cm.) between phase centers. These bus bars just described lead from transformers to flexible cables. The latter are about 20 feet (6 m.) long, consisting of nine 1,000,000 circular mil stranded copper cables for each phase. The flexible cables connect in turn to bus bars on furnace proper, the latter being made up of six copper bars ¼" x 6" (0.6 x 15 cm.) in each phase, running first vertically and then horizontally to the electrode clamps.

In case of both the bus bars between the transformers and the flexible cables, and also the bus bars on the furnace itself, the ¼ x 6" (0.6 x 15 cm.) copper bars were spaced by means of ¼ x 3 x 6 in. (0.6 x 7.5 x 15 cm.) copper spacers. These spacers have all been replaced by vulc-asbestos spacers. In addition, mica insulation was placed between the various bus-bar leads in such a way that the different parts were isolated and made to act as nearly as possible independently from one another. We find that these small changes have made a great change in operation of furnace. From all indications it would appear that the drop in voltage found by Mr. Meyer has been much reduced. This point will be more clearly established by a series of tests which will be undertaken in the very near future.

At any rate, it is safe to assume that part of the drop was due after all to skin effect, and that it was not entirely due to induction set up in the steel construction at rear and top of furnace, as Mr. Meyer stated in his paper.

Under the circumstances, it would be much better to do away with the solid bus construction entirely. The later Heroult furnaces are now constructed as is our 3-ton furnace, where the flexible cables are carried direct to the upper part of the steel structure at back of the furnace. It would seem even better to us to carry the flexible cable directly through to the electrode clamps. There would of course be some induction set up in the steel structure, but we do not believe there would be as much voltage drop as there is now. At any rate, as now constructed, our furnaces are running much faster than formerly, and our current consumption is regularly lower than it was before. On one run of 24 hours, 11 heats were taken from the 3-ton furnace. Our average current consumption for the week, including all delays and stops, is

running under 625 kw. hours per ton. Since our work is light, and our metal must be brought to a very high temperature, we consider this a very low consumption.

With our tonnage brought to this high figure, our floor capacity is taxed to the utmost. An additional furnace would therefore be superfluous and uneconomical. The only opportunity for "reversed duplexing" in our own shop would be to change the 3-ton furnace to basic lining. Under present pressure of work this if of course impossible, and the actual trial of duplexing must therefore wait.

There is one other point referred to in the writer's former paper which I desire to touch upon here, namely, the great possibility of the electric furnace in production of the various steel alloys. This one feature is perhaps of greater value and interest to the makers of tool steel, but I am firmly convinced that there are wonderful possibilities in the manufacture of heat-treated alloy-steel castings. This is a field which is almost untouched and is well worth investigating.

I wish to quote for a moment from Major C. M. Wesson's paper on "Steel Castings for Ordnance Construction," presented at the Boston Meeting of the American Foundrymen's Association in September.

Major Wesson says in his introduction: "Special heat-treated and alloy steel castings offer a wide field of endeavor and our knowledge is rapidly increasing concerning them. The prediction is ventured that eventually they will replace the high-grade intricate forgings, just as the plain casting, as we know it today, has supplanted, in a large measure, the plain forging. We have, however, not time to dwell on them here."

I agree with this statement thoroughly, although I do not draw the line just where Major Wesson does. Small forgings will always continue to be used and will prove cheaper than steel castings wherever they are needed in sufficient quantities, so that die-cost will be a small item for forging. As forgings increase in size or in intricacy, a point is reached where die cost is so excessive and manufacturing cost so high that a steel casting can be made for less money than a forging. But even so, the user or buyer of this class of forging must still have to be satisfied on two very

important points before he would substitute a casting for any forging; and these two points are:

(1) He must know definitely that the castings have been made by careful scientific methods, so that soundness and absence of imperfections can be guaranteed.

(2) The metal must be of very high physical quality, and in many cases demands will be such that only a heat-treated alloy casting would fill.

During past months we have been experimenting along this line and wish to refer briefly to some wonderful tests we have been getting from vanadium steel. These tests have been obtained repeatedly, so that we are confident that we can reproduce them commercially.

The tests we refer to are the following:

	No. 1		No. 2	
Ultimate strength.	102,000 lb.	74 kg./sq. mm.	103,800 lb.	74 kg./sq. mm.
Elastic limit.....	81,500 "	57 " " "	84,000 "	59 " " "
Elongation in 2"..	23 percent	.....	21 percent	.....
Reduction in area.	48 "	.....	47 "	.....

There is just one more point which I desire to bring to your attention. In the discussion of my paper before this Society in May, Prof. J. W. Richards spoke in part as follows:[5]

"Regarding the general question of the fitness of electric furnace steel for steel castings, for the information of the Naval Consulting Board I sent a questionnaire to about forty or fifty of my friends in the steel business, asking how a better class of steel castings could be obtained. About nineteen out of twenty of these answers were that if they would specify electric furnace steel for their castings that, other things being equal, there was a far better chance of getting a fine casting from electric furnace steel than from any other class of steel."

This statement of Prof. Richards sounds strangely prophetic, when read at this time in the light of what has happened since these words were spoken. Referring to our own experience, we are furnishing considerable quantities of army castings under Class No. 2 and No. 3 specifications, and are also making navy castings under Class "B" specifications, and are having little trouble in meeting these specifications.

[5] Trans. Am. Electrochemical Soc., 1917, 31, 80.

We do not want to give the impression that these results are being obtained without any particular effort on our part, for quite the contrary is the fact. The heats are held for analysis before pouring, and every possible effort is made to have carbon and manganese where we desire them, before the heat is poured. Annealing is carefully carried out in new ovens recently installed, and here again every care is taken to see that annealing is exactly what we have planned it to be.

The result of these precautions is that we are passing army and navy tests regularly. We do not hesitate to say, however, that with the same precautions we would fail on many of the tests were we using converter steel. At least that was our experience when we made converter steel, and it is our belief that many converter foundries are having this same trouble at the present time.

The tests that we are obtaining are interesting in one way. They rather emphasize the fact that the specifications were not written for electric steel. For instance, Class No. 2 army specifications—

	Call for		We obtain	
Ultimate strength.	75,000 lb.	53 kg./sq. mm.	75,000 lb.	53 kg./sq. mm.
Elastic limit.....	35,000 "	25 " " "	40,000 "	28 " " "
Elongation in 2"..	15 percent	.....	20 percent	.....
Reduction in area.	20 "	.....	30 "	.....

In the same way Class "B" navy specifications—

	Call for		We obtain	
Ultimate strength.	60,000 lb.	42 kg./sq. mm.	65,000 lb.	46 kg./sq. mm.
Elastic limit.....	27,000 "	19 " " "	35,000 "	25 " " "
Elongation in 2"..	22 percent	.....	30 percent	.....
Reduction in area.	30 "	.....	40 "	.....

In addition to the above, a 120°-bend test is required, which usually shows a bend up to 170° or 180°.

You will note in each case we obtain well over 50 percent of the ultimate strength as elastic limit, while both the army and navy specify about 45 percent. Average tests of electrical steel will run pretty close to 60 percent.

This army and navy steel casting experience is really a great education for many of the steel foundries, and is bound to have a marked influence upon the industry after the war. Instead of a statement of hoped-for qualities, competition will demand physical

test coupons, which must stand certain tests and the castings will be accepted or rejected on the basis of these tests. It is needless to add that castings sold under such an arrangement must necessarily be of a uniformly higher grade than the average run of steel castings now sold.

DISCUSSION.

F. J. Tone[1]: Mr. Flinterman's statement of his electrical conditions brings up a very important question in electric furnace operation, and that is bus-bar and electrode-holder design. Mr. Flinterman does not state the frequency at which he operates at Detroit, but I understand it to be 60 cycles. A furnace may operate with entire satisfaction at 25 cycles and at 60 cycles give very low power factor and numerous troubles from skin effect and mutual induction of bus-bars and cables. While the design described may be satisfactory for 25 cycles, this being the usual frequency at which Heroult furnaces are operated, it is faulty in a number of particulars for the higher frequency.

In every case bus-bars should be interlaced from the transformer to the points of the *delta* where the cables are attached. From this point to the electrode interlacing is impracticable; therefore when designing for 60 cycles the shortest possible conductor length must be worked out to get a satisfactory power factor, and a cable length of 20 feet (6 m.) would seem to be excessive. A length of 10 or 12 feet (3 or 3.5 m.) for the flexibles is common in furnaces of 6000 kw. and ought to be sufficient in this case. The bars on the furnace are stated to be spaced ¼ inch (6.5 mm.) apart. This is very faulty designing from a standpoint of mutual induction, and an excessive current would be carried by the outside bars, certainly two or three times the current carried by the inner bars. A spacing of 1 or 1¼ inch (25 or 30 mm.) is advisable. The ideal arrangement is to replace bars on the furnace with a solid water-cooled conductor of tubular section.

The design of bus-bars and electrical accessories for higher

[1] Works Manager, The Carborundum Co., Niagara Falls, N. Y.

frequencies is one involving some difficult principles in engineering and mathematics, and I hope we may induce some of our engineers to treat this subject in the near future in an exhaustive paper.

The next point and to me the most stimulating one in Mr. Flinterman's paper is his statement of the possibilities of the electric furnace in the production of alloy steels. The automobile gave the first impetus to the use of alloy steel, and under the stimulus of war demands for various munition purposes the output has probably been quadrupled. Still alloy steel is a great luxury, and is only used where the engineer wishes to take care of the highest strains with a minimum of weight in some vital part of the mechanism. Our aim should be to make alloy steel one of the common materials of engineering.

C. G. FINK[2]: Mr. Flinterman has done a great deal of work along this line, and I am very glad to see that we can include another of his papers in our next Transactions. May I ask Mr. Laundry what are the prospects for electrical steel in Birmingham? I understand that there is a ferro-manganese furnace in operation, but it is used chiefly as a heating furnace to keep the charge melted. What are the prospects of making ferro-manganese right here in Birmingham?

MR. LAUNDRY: I don't think there is very much chance at the present time. They are doing that at Anniston right now, and you will see it tomorrow. As far as the Birmingham district is concerned, we have not contemplated any step in that direction.

C. G. FINK: On account of the cost of power?

MR. LAUNDRY: To a certain extent, yes, and in the big commercial products where there is tonnage, we have not considered alloy steel of any kind, and we figure that with the triplexing we are going to start this year, we will make a steel commercially as good or nearly as good as the alloy steel.

MR. CONGRAVE: Some steel men assert that common carbon steel can be made as good as the so-called alloy steel, and can be made cheaper.

[2] Head of Laboratories, Chile Exploration Co., New York City.

A paper presented at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918, President Fink in the Chair.

CERTAIN HYDRO-ELECTRIC POWER POSSIBILITIES IN THE PROVINCES OF QUEBEC AND ONTARIO, CANADA.[1]

By Louis Simpson.[2]

Abstract.

A description of possible hydro-electric power developments of the waters of the Ottawa River, near the City of Ottawa, and of the waters of the St. Lawrence River, near the City of Montreal, Canada.

In these days of hydro-electric power shortage, any information as to possible future development of hydro-electric power must be of interest.

Only of late years has it been recognized that more is required of a hydro-electric power development than the existence of a large minimum supply of water under conditions that will permit its use under a reasonably high head, a fairly low cost of development and a convenient location. It is now recognized that engineering conditions should be such that troubles from ice shall seldom occur and shall at all times be small.

Troubles from ice have during the last few years become a factor of an importance too considerable to be ignored. Hydro-electric powers which, when only partially developed, were comparatively free from troubles caused by ice, have, since their complete development, been subjected to such serious ice troubles as to change the cost of an apparently low-priced power into one of high price, when the loss caused by closing down was added.

[1] Manuscript received February 25, 1918.

[2] Industrial Engineer, Ottawa, Canada.

In Canada and in the northern section of the United States there are now to be found but few undeveloped hydro-electric power propositions of magnitude, that when properly developed, and at a reasonable cost, will be comparatively free from ice troubles.

Of such power propositions located in Canada, and reasonably near to the United States, that one situated upon the Ottawa River, 32 miles west of the City of Ottawa, known as he Chats Falls, as probably the best. It is possible, at these falls, to develop between 110,000 and 120,000 E.H.P. The possible head is 50 feet and troubles from ice can be reduced to a minimum. The half of the falls situated in the Province of Ontario, belongs to the Hydro Electric Power Commission of Ontario, the half situated in the Province of Quebec, is owned by several proprietors, but as these are ready to co-operate with the Hydro Electric Commission to secure a joint development, upon terms already arranged, the property is capable of speedy development.

The Canadian Northern Transcontinental Line, now owned by the Canadian Government, passes close by the south end of the falls, whilst very short branch lines could connect the falls with the transcontinental lines of the Canadian Pacific and of the Grand Trunk Railways.

Excellent sites for large works exist at both ends and at the center of the falls; these can be purchased at reasonable prices.

Another proposition, one of great magnitude and one that, because of its magnitude may not be so quickly made available, is that which is possible, through the construction of a canal from Lake St. Francis to a power house located on the Lake St. Louis, both these lakes being enlargements of the River St. Lawrence.

The possible head will be 80 feet, and it will be possible to develop 1,000,000 H.P.

This development, also, if properly engineered, would be free from ice troubles.

Unfortunately it is not financially possible to undertake this development unless the development be undertaken conjointly with the construction of a deep navigation canal, such a one as will eventually be required to enable the boats that will pass through the New Welland Canal, now in course of construction,

to pass from Lake St. Francis to Lake St. Louis. Along with the construction of such a navigation canal, a power canal could be constructed (each interest bearing its fair share of the total cost of the canal). The cost of a joint canal would be very considerably reduced over the cost of two separate canals. Even with such a reduced cost, the construction of such a canal would only be financially possible were a very considerable portion of the total possible power development (from 25% to 50%) to be rented on completion.

One of the hydro-electric power developments using the waters of Lake St. Francis has an historical interest. The first hydro-electric power development operated in Canada was undertaken on one of the discharges from Lake St. Francis at Valleyfield, by the Montreal Cotton Co. This development is particularly interesting, because, in this power house was installed the first direct-connected electric generator ever made. This generator was built by The General Electric Co. at their Schenectady, N. Y., works, upon an agreement with the then general manager of the Montreal Cotton Co. (whose idea it was) that the builders were to be relieved of all technical and financial responsibility. That the installation was a success is evidenced in every modern hydro-electric power house.

From the waters of Lake St. Francis the following hydro and hydro-electric power is developed or else will be developed in the near future. This power is over and above the possible 1,000,000 H.P. already mentioned.

Montreal Cotton Co.	10,000 H. P.
Provincial Light, Heat and Power Co.	15,000 H. P.
Cedar Rapids Mfg. and Power Co.	200,000 H. P.
Power Development Company	100,000 H. P.
Canadian Light and Power Co.	15,000 H. P.
Total	340,000 H. P.

N. B.—Of this total about 140,000 H. P. is under construction or the construction is to be commenced at an early date.

The immediate district is excellently provided with water navigation and railway facilities. Water navigation connects with Montreal and the sea, to the East, and with Toronto and the Great Lakes to the West.

The railway systems available are the Grand Trunk, the Canadian Pacific and the New York Central.

Land suitable for the erection of works can be purchased at reasonable prices.

With such possibilities of power development in the future the requirements of the users of large blocks of hydro-electric power should not long remain unfilled.

DISCUSSION.

C. G. FINK[1]: The question of ice seems to worry our engineers of the North a good deal. I wonder whether the question of ice need be considered by the Aluminum Company of America in the development of the power plant we inspected this morning?

N. T. WILCOX[2]: For the information of the people here, I want to state that we have been operating the Mississippi River Power plant at Keokuk, Iowa, where we get some very low temperatures at times. That has been especially true this past winter. Of course we draw from deep water in our forebay and our head gates are covered, and I want to make the statement here that since we started up nearly five years ago we have not had one particle of trouble with ice.

C. G. FINK: That sounds good; can anybody present tell us about the Tennessee development as regards the ice question?

C. M. JESPERSON[3]: In regard to the ice troubles in this section of the country, I am familiar with the country around Birmingham, Ala., they have absolutely no ice troubles, as it does not get cold enough for rivers to freeze. I was located a couple of years in West Virginia, and during that time there was only one morning that I saw any ice in the river. Under these circumstances there should be no troubles with ice in this section of the country.

[1] Head of Laboratories, Chile Exploration Co., New York City.
[2] Manager, Mississippi River Power Co., Keokuk, Iowa.
[3] Secretary-Treasurer, Southern Manganese Corp., Anniston, Ala.

H. E. RANDALL[4]: It seems wrong to let some of the statements presented in this paper go unchallenged. We would be led to believe that in Canada and in the northern section of the United States there are now to be found but few undeveloped hydro-electric power propositions of magnitude.

I am afraid the writer has never been through the State of Maine, or through the northeastern portion of the Province of Quebec. Last fall at Pittsburgh I mentioned the great undeveloped water powers on the rivers flowing into the lower St. Lawrence River and draining the big country between Labrador and the Gulf of St. Lawrence. One of these possible developments, you all have probably heard about, viz., the proposed development by the Duke interests of the water power of the "Grand Decharge" of Lake St. John into the Saguenay River. The above territory abounds in water powers which, owing to the character of the country, are in general situated near the Gulf of St. Lawrence and are of considerable head, from 100 to 200 feet.

The last report received from the Commission of Conservation of Canada shows that about 17,000,000 H.P. is available for economic hydraulic development in Canada, of which today less than 3,000,000 is developed. I therefore think that on the part of Canada and the United States we ought not to take the statements set forth in this paper at their face value.

LOUIS SIMPSON (*Communicated*): I did not state that there were no desirable water powers yet undeveloped "in Canada and in the northern section of the United States." I still insist that there are but few such powers in the district designated which are "of magnitude, that when properly developed and at a reasonable cost, will be comparatively free from ice trouble."

I am aware of the water powers that are being and may be developed from the discharge of Lake St. John, but their existence cannot affect my contention. I am aware of the water powers that may be developed from the waters of the rivers that flow from the height of land south to the St. Lawrence; these possible water powers certainly do not affect my contention. With all of these, or with nearly all, there may be expected con-

[4] Power Sales Engineer, The Shawinigan Water and Power Co., Montreal, Canada.

siderable trouble from ice, as every hydro-electric engineer of experience will admit.

The undeveloped water powers of Canada, given by the Commission of Conservation as about 14,000,000 H.P., chiefly consist of water powers situated in the wilderness. It is evident that the existence of such powers, since from their location they cannot at present be developed at a reasonable cost, does not make my statement incorrect, whether they be troubled with ice or not.

An address delivered at the Thirty-third General Meeting of the American Electrochemical Society, at Knoxville, Tenn., April 30, 1918.

THE LARGER UNDEVELOPED WATER-POWERS OF TENNESSEE.

By J. A. Switzer.[1]

The power streams of Tennessee are nearly all of them tributaries of the Tennessee River, and, taking their rise either in western Virginia, North Carolina or Georgia, flow in a southwesterly direction down the western slopes of the Appalachian Mountains. To enumerate, beginning at the north, one encounters first the Powell River, then the Clinch River, of which the Powell is a tributary, and which itself flows into the Tennessee River at Kingston, 35 miles (59 km.) southwest of Knoxville. Next is the Holston River, near the headwaters of which is located the city of Kingsport, and of which the Watauga is a tributary. The Holston, by its confluence with the French Broad River at Knoxville, forms the Tennessee.

The French Broad rises not far from Asheville, N. C., and flows past that beautiful city. The important tributaries of the French Broad are the Nolichucky and the Pigeon Rivers, both of which reach it near Newport, Tennessee, the Nolichucky from the north and the Pigeon from the south. Proceeding south, the next stream of importance reached is the Little Tennessee River, of which the tributaries in North Carolina are the Nantahala, the Tuckasegee and the Cheoah, and in Tennessee the Tellico River and Abram's Creek. Last is the Hiwassee River, with its principal tributary the Ocoee.

Existing power developments are located on the Watauga, the Nolichucky, the French Broad and the Ocoee Rivers, besides which are two others within the State, one on the Tennessee River itself at Hale's Bar, 39 miles (63 km.) below Chattanooga, and one on the Caney Fork, a tributary of the Cumberland River. Beside these should be mentioned the very extensive develop-

[1] Professor of Hydraulic Engineering, University of Tennessee, and Hydraulic Engineer of the Tennessee State Geological Survey. Manuscript received July 30, 1918.

ments, now in process of construction, of the Aluminum Company of America, on the Little Tennessee River and those of its tributaries which lie in North Carolina.

A brief description of the existing plants may be of interest.

Beginning again at the north, on the Watauga River, 18 miles (30 km.) south of Bristol, is located the 3,200-horsepower plant of the Watauga Power Company, whose power output is transmitted to Bristol for consumption in that city.

Near Greenville, on the Nolichucky River, is the plant of the Tennessee Eastern Electric Company. The present installed capacity is 3,600 horsepower, to be increased later to 14,000 horsepower. This power is consumed in the towns of Johnson City, Greenville and Jonesboro.

On the French Broad River (in North Carolina, not Tennessee) near Asheville, are the three plants of the North Carolina Electrical Power Company, aggregating 7,500 horsepower of installed capacity. This power is used in Asheville and nearby towns.

The most extensive public service power company in Tennessee is the Tennessee Power Company. On the Ocoee River, this company has built two plants, the one with 25,000 horsepower and the other with 20,000 horsepower installed capacity. At Rock Island, on the Caney Fork River, a tributary of the Cumberland, 75 miles (125 km.) southeast of Nashville, is located a third plant containing one 12,000-horsepower unit. Besides these three, the company operates, under lease, the Hale's Bar plant of the Chattanooga and Tennessee River Power Company, in which are installed 14 turbines aggregating a capacity of 54,000 horsepower. The company operates more than 1,000 miles (1,650 km.) of transmission lines, serving the cities of Chattanooga, Knoxville and Nashville, and the Aluminum Company of America at Maryville, and the American Zinc Company at Mascot. Five auxiliary steam plants aggregating 54,000 horsepower also serve the system.

The hydro-electric plants on the Ocoee River merit description since they are representative of two types of development indigenous (so to speak) to the Appalachian region, where nature presents man with no ready-made Niagara Falls, but where fall must be artificially concentrated, by the building either of a high

dam of which the height constitutes the head rendered available for power, or of a diversion dam and flume line whereby the same end is gained.

The first of these plants is that at Parksville. Here a concrete dam 110 feet (33 m.) high was built, having a crest 800 feet (240 m.) long and containing 155,000 cubic yards (115,000 cu. m.) of concrete. The power equipment consists of 5 units of 5,000 horsepower capacity each. The power house is built integral with the dam. The pool created is 8 miles (13 km.) long and covers an area of 2,200 acres (8.5 sq. km.). The total storage is 100,000 acre-feet (140,000,000 cu. m.), but the draw-down is only about 31,000 acre-feet (40,000,000 cu. m.). This storage will yield approximately 3,500,000 horsepower hours, or 9,700 horsepower for 12 hours per day for 30 days. The tributary drainage area is 602 square miles (1,500 sq. km.).

The second plant, known as the Caney Creek plant or "Ocoee No. 2," consists of a rock-filled timber crib diversion dam, a timber flume which discharges into a forebay, and from which two steel penstocks lead down the steep mountain side to the two turbines in the power house. The power house is located about one mile above the head of slack water due to the Parksville development. The timber dam is 40 feet (12 m.) high and 385 feet (115 m.) long. The flume, 5 miles (8 km.) long, measures 10 feet 9 inches (3.2 m.) by 14 feet 2 inches (4.25 m.) inside. Having a slope of 3.4 feet (1 m.) per mile, it was designed for a capacity of 1,200 second-feet (34 cu. m/sec.). The flume required for its construction 1,130,000 feet (2,450 cu. m.) of timber. It rests for most of its length upon a bench blasted out of the mountain side, and where deep gullies or tributary streams are encountered it is carried across on structural steel trestles. The mountain side was in many places so precipitous that in making the location the surveyors had to be lowered to the grade by ropes from above. The plant contains two turbines of 10,000 horsepower capacity, each served by an 8-foot steel penstock, and the effective head is 260 feet (78 m.). The area of the tributary catchment basin is 515 square miles (1,300 sq. km.).

The Hale's Bar plant of the Chattanooga and Tennessee River Power Company is of interest to the engineer chiefly because of the enormous difficulties which were encountered in securing

adequate foundation for the dam and power house. The geological formation is Bangor limestone, and the bed rock was found to be rather badly fissured. By reason of this condition, the cost of the development greatly exceeded the estimated cost. Over 200,000 bags of cement were used in grouting fissures in the bed rock.

The dam is 40 feet (12 m.) high and has an over-all length of 2,500 feet (750 m.), of which length 1,200 feet (360 m.) constitutes the spillway section. The installation, as originally designed, was to consist of 14 units, of 4,200 horsepower capacity each. A unit consists of three turbines mounted on a vertical shaft. After ten of these units had been installed, it was decided to substitute, in place of the remaining four, single-runner turbines which, though of somewhat smaller capacity, should realize higher efficiency under low-flow conditions.

Although the pool created by the dam extends for a length of 33 miles (55 km.), very little pondage is afforded, and the plant is subject to the vicissitudes of wide variations in stream flow. The river discharge varies between the limits of 4,300 second-feet and 500,000 second-feet (123-14,300 cu. m./sec.). With low flow conditions the plant capacity is limited by reason of insufficiency of water, and with flood-flow conditions it is limited by loss of head. With the installation as originally planned, the variation in plant capacity would have been in accordance with the following table; however, with the change as noted above, the maximum capacity is reduced to 54,000 horsepower, and the low-flow capacity is somewhat increased.

River Discharge		Head on Wheels		Power in Horsepower at Switchboard	
Cu. Ft./Sec.	Cu. M./Sec.	Ft.	M.	Av. 14 Hrs.	Av. 10 Hrs.
6,700	190	39.5	12.05	16,800	40,000
9,400	268	39.0	11.90	16,800	52,000
17,800	508	37.7	11.48	53,500	58,800
27,000	770	36.8	11.21	58,800	58,800
159,000	4540	27.6	8.40	58,800	58,800
250,000	7140	22.9	6.97	46,800	46,800
300,000	8550	20.3	6.18	36,500	36,500

(Data furnished the author by John Bogart, Chief Engineer, Chattanooga-Tennessee River Power Co.)

The power developments of the Aluminum Company of America now in progress on the Little Tennessee River and those of its tributaries which lie in North Carolina, will take rank with the foremost water powers of the country. The development as a whole is notable, especially for the thorough-going study which was bestowed upon it before any work of construction was begun. The plan contemplates the erection of a series of dams, each located at the head of slack-water due to the dam next below it. The dam first to be completed will be the second of the series. This dam, located at the mouth of the Cheoah River, is at the present time about 85 per cent. completed. The dam, with a height of 200 feet (60 m.) and length of crest approximately 850 feet (255 m.), will be the highest overfall dam ever built. At times of maximum flood discharge there will be dissipated at the toe of the dam something like one million horsepower of energy.

The power equipment at the Cheoah dam will consist of 4 units of 24,000 horsepower capacity each. Three of these are now being erected, and the fourth will not be placed until some of the storage to be effected by dams higher up is rendered available. The Cheoah dam itself will afford virtually no storage. The tributary drainage area is 1,840 square miles (4,600 sq. km.).

Near Alcoa, Tennessee, construction has been started on the dam which will constitute the first of the series. This dam, too, will be 200 feet high (60 m.).

The total power developments when completed will yield something over 400,000 horsepower.

The site of the third dam is definitely fixed, but not its height. The topography of the site would lend itself to a dam 250 feet (75 m.) or more high; and the final decision as to the height to be adopted waits upon the experience to be gained at the Cheoah dam. Whatever this height will be, and whatever the total number of dams to be constructed, I am authorized to say that not one foot of fall nor one second-foot of run-off will be wasted when the whole scheme of development is finally completed.

The thorough-going study of its water-power holdings pursued by the Aluminum Company (with the details of which the author is familiar) and the bold policy of its utilization could not fail to inspire a breadth of vision in the making of a study of the still undeveloped water powers of Tennessee.

In the presentation of this study the author must perforce make clear, at the outset that nothing more than reconnaissance surveys have yet been made of most of these water powers. But even such surveys have made possible the outlining of broad schemes of power generation which further field work no doubt may modify though probably not altogether upset.

No broad-gauge policy of water power development could be built up unless the river systems were considered as such; nor could any practical scheme be devised for the full utilization of the potential power now lying dormant without giving full consideration to such limiting conditions as the locations and elevations of railroads and railroad bridges, the agricultural value of overflowed lands, etc. In the case of that section of the French Broad River extending from near Newport, Tennessee to Asheville, North Carolina, the existing location of a railroad closely paralleling the stream prevents any possible utilization of the river, except for relatively small developments. Fortunately, however, it so happens that on the other important power streams in this region the railroads, while establishing certain limitations, do not altogether destroy the power possibilities of the rivers.

All of the possible power sites have been visited by the author, and careful cross-sections of all that appeared promising were made by surveying parties under his direction; and sea-level elevations were obtained by tying the site in each instance to some Government bench-mark.

Profiles of several of the rivers have been taken by the Corps of Engineers, U. S. A., and use has been made of the data available from this source. This information covers the Clinch River from its mouth to the railroad crossing near Ore Bed, the Holston River from Knoxville to Kingsport, the Tennessee River from Chattanooga to Knoxville, the French Broad from Knoxville to Leadvale, the Little Tennessee River from its mouth to Silver Creek, and the Hiwassee River from its mouth to Savannah Ford. Also, the profile of the Ocoee River taken by the United States Geological Survey has been consulted.

The author's cross-sections of most of the selected sites are presented in Figs. 14 to 30, inclusive.[2]

[2] Figs. 14 to 30 have been omitted from our Transactions to save space and paper. Any engineers who wish a copy of the paper including these figures may obtain such by application to the author, at Knoxville, Tenn., or to the Tennessee State Geological Survey, at Nashville, Tenn.

A consideration of the topography of any site, the relative elevations of the site itself and of railroad crossings, or existing power developments higher on the stream, fixes in each case the feasible height of dam. A general study of the features of the situation determines the type of plant best adapted to develop the power at each site. In some instances more than a reconnoissance survey has been made, either by the author himself or by some other engineer who has made the preliminary study for an existing development company, as for instance in the case of the Hiwassee Power Company.

As a result of such study, the general scheme of development which is shown on the accompanying map has been evolved, and for the sake of clearness may be briefly described under appropriate captions.

CLINCH AND POWELL RIVERS.

These rivers constitute a system lending itself to splendid power development. Four miles above its mouth the Clinch River receives the water of Emory River. Just below the mouth of Emory River is a site (Dam No. 4) and just above it a second (Dam No. 21).

The height of dam No. 4 is limited to 45 feet (13.5 m.) by the location of the city of Harriman, on the Emory River. The height of dam No. 21 is limited to 85 feet (25.5 m.) by the location of the Louisville and Nashville Railroad near Dossett. The drainage area tributary to the lower site is 4,420 square miles (11,000 sq. km.), and to the upper 3,551 square miles (8,800 sq. km.). The upper site is undoubtedly the more attractive, owing to the higher permissible head.

The Clinch River has been declared navigable as far as Clinton. Consequently a lock would be required at either site, and, under the present laws, also a special act of Congress permitting the power development.

The map shows the approximate flow line of the pool which dam No. 21 would create. Dam No. 21 would create slack-water nearly to the town of Clinton.

The next power site (Dam No. 3) is located on the Clinch River 5 miles (8 km.) east of Coal Creek. Here is a site for a dam 175 feet (53.0 m.) high, which will back water up the Clinch

River for a distance (as the river winds) of some 42 miles (70 km.), and up the Powell River a distance from its confluence with the Clinch River of about 35 miles (58 km.). The height of the dam is fixed by the crossing of the Southern Railway over the Clinch River at Clinch and over the Powell River at Ore Bed. The dam would create an enormous storage, and would flood land of but little agricultural value. Taken in conjunction with the two higher dams next to be described, the storage would be such as to yield at dam No. 3 a completely regulated run-off, so that the turbines might utilize the mean annual run-off of the average year. The drainage area at dam No. 3 is 2,885 square miles (7,200 sq. km.).

Dam No. 2 on the Clinch River is located just above the railroad crossing at Clinch, in fact only one mile (1.6 km.) above the head of the pool from dam No. 3. Its height could be 160 feet (48 m.), this limit being determined by the location of the town of Clinchport. The drainage area is 1,548 square miles (3,870 sq. km.).

Dam No. 1 on the Powell River is located just above Ore Bed, immediately above slack-water from dam No. 3. Its height is limited by no consideration other than that of the topography of the site, and the economic value of the power which it would yield. While a dam over 200 feet (60 m.) high could be built without requiring an inordinate quantity of concrete, the drainage area which is tributary, namely 700 square miles (1,750 sq. km.), would probably not warrant very great height; and the figure here adopted is 180 feet (54 m.). A dam of this height would require about 274,000 cubic yards (211,000 cu. m.) of concrete. The project should be considered in conjunction with dam No. 3, as its storage could contribute greatly to the value of project No. 3.

THE TENNESSEE RIVER.

The Corps of Engineers, U. S. A., has devoted years of study to the problem of maintaining the navigability of the Tennessee River between Chattanooga and Knoxville, and incidental to this study has been the consideration of power development as well. In this reach of the river, however, there are no conspicuous power sites which offer commercially attractive possibilities. Just above Knoxville, scarcely outside the city limits in fact, there is

a site where a 40-foot (16 m.) dam could be built, requiring but 51,000 cubic yards (40,000 cu. m.) of concrete, and which would yield considerable power. The site is shown on the map as dam No. 7. The pool would extend for 6 miles (10 km.) up the Holston River and for 18 miles (30 km.) up the French Broad, and would inundate nearly 15,000 acres (60 sq. km.) of land, much of which is valuable agricultural land. The drainage area is 8,990 square miles (22,500 sq. km.). Without the development of considerable storage on the tributary rivers, such as the dams still to be described would effect, it is doubtful whether this project would be a financial success. In other words, the project is one for the future, and no doubt will ultimately be utilized.

THE HOLSTON RIVER.

Two excellent sites are available on this river. Site No. 6 is located near Strawberry Plains. The railroad bridge near the station of Holston limits the height of the dam to 90 feet (27 m.). However, with a drainage area of 3,656 square miles (9,140 sq. km.), this is an attractive power site. No. 5 dam is located just above Holston station. A height of 110 feet (33 m.) is permissible, and slightly less concrete will be required than went into the construction of the 110-foot (33 m.) dam of the Tennessee Power Company at Parksville. The drainage area at this site is 3,392 square miles (8,490 sq. km.). This dam will back water to the railroad bridge at Austin Mills, and while there may be additional sites above this point, the location of railroads precludes any additional development. No water power of any magnitude appears to be available at or near Kingsport.

THE FRENCH BROAD AND NOLICHUCKY RIVERS.

Dam No. 7 (at Knoxville) would back water up the French Broad River nearly to the mouth of Boyd Creek. Here is a site for a dam (dam No. 12), the height of which is limited by the location of the town of Sevierville (on the Little Pigeon River) to 45 feet (13.5 m.). Such a dam, however, requiring but 50,000 cubic yards (38,000 cu. m.) of concrete for its construction, and having back of it a drainage area of 4,983 square miles (12,400 sq. km.), offers most attractive possibilities. It would flood about 12,000 acres (48 sq. km.) of land, most of which is valuable farm land.

Dam No. 12 backs water nearly to the town of Dandridge. Here is a site (No. 11) for a 75-foot (22.5 m.) dam. The height is fixed by the railroad bridge near Leadvale, but water could be backed under this bridge, and slack-water would reach up the French Broad, a little above the mouth of the Big Pigeon, nearly to Newport, and up the Nolichucky nearly to Soloman's Ferry (another power site). This site at Dandridge appears to be very attractive. With a drainage area of 4,455 square miles (11,100 sq. km.) a 75-foot (22.5 m.) dam would yield good power. The dam would contain about 150,000 cubic yards (116,000 cu. m.) of concrete and would flood approximately 9,000 acres (36 sq. km.) of land, nearly all of it of good agricultural quality.

On the Nolichucky River are located three excellent sites. Dam No. 10 at Soloman's Ferry would be 70 feet (21 m.) high, and back water to Bird's Hill, where would be located dam No. 9, 100 feet (33 m.) high. The Bird's Hill site limits the height of dam No. 10. The Bird's Hill dam is limited to 100 feet (33 m.) by the location 15 miles (25 km.) higher up of the dam of the Tennessee Eastern Electric Co. Dam No. 10 subtends a drainage area of 1,752 square miles (4,400 sq. km.), and dam No. 9 of 1,342 square miles (3,350 sq. km.) The plant of the Tennessee Eastern Electric Company, above project No. 9, with a crest height of 70 feet (21 m.) and a drainage area of 1,140 square miles (2,850 sq. km.), will contain equipment of 14,000 horsepower capacity.

Much higher on the Nolichucky, near Embreeville, is located project No. 8. This project would involve building a dam 70 feet (21 m.) high (containing but 59,000 cubic yards (45,000 cu. m.) of concrete) and a steel pressure pipe 10,000 feet (3,000 m.) long. This would render available a head of 132 feet (40 m.). Having a drainage area of 780 square miles (1,950 sq. km.), the project would compare most favorably with the Parksville plant of the Tennessee Power Company.

THE PIGEON RIVER.

Power development on the lower reaches of the Pigeon River is prevented by the location along its banks of a railroad. However, the middle section of the river offers a power site attractive in the extreme. Here the river flows through banks so narrow

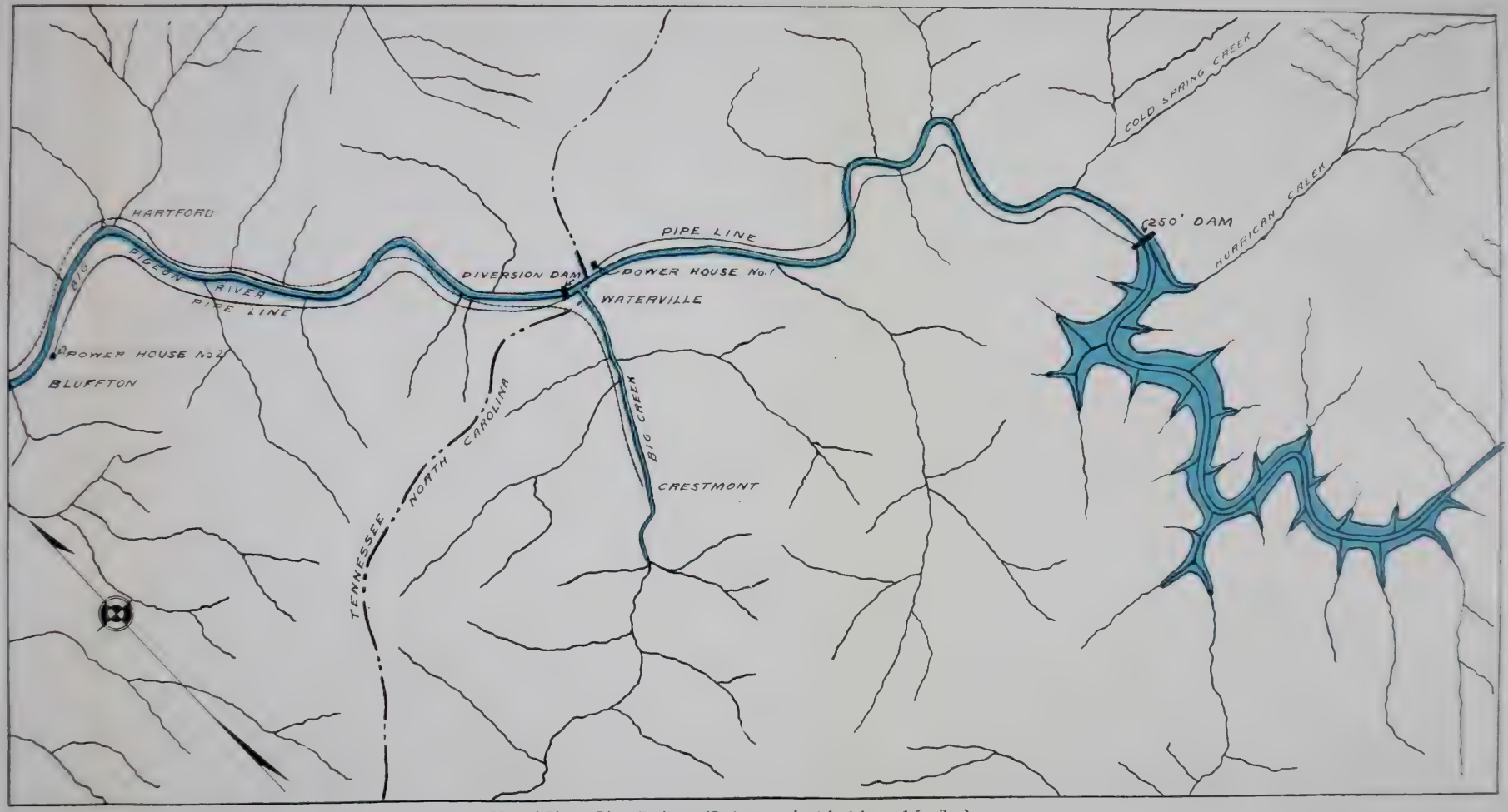


FIG. 1. Map of Pigeon River Project. (Scale approximately 1 in. = 1.6 miles.)

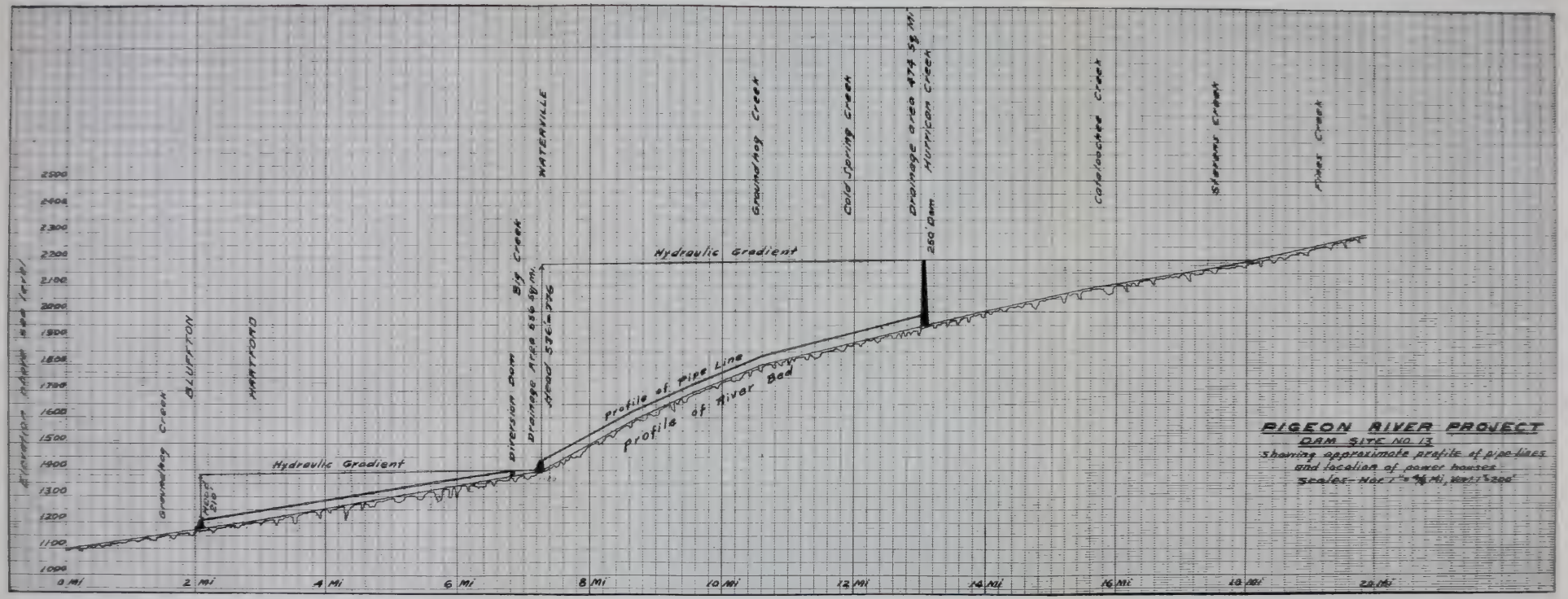


FIG. 2. (One square equals horizontally one-fifth mile, vertically 50 feet.)

and steep as almost to merit being called a canyon. For a distance of 18 miles (30 km.) the fall of the river averages 65 feet per mile (12 m. per km.) and for six miles (10 km.) 100 feet per mile (19 m. per km.). The best treatment of this project would be to build a dam high enough to afford some pondage, and a steel penstock, several miles long. Such a treatment is shown by the map (Fig. 1) and profile (Fig. 2). Here is shown a dam 250 feet (75 m.) high located 5¾ miles (9.5 km.) above Waterville, at the mouth of Hurricane Creek. Leading from the dam is shown a pressure pipe, terminating in a power house at Waterville. Granting a slope of the hydraulic gradient of 5 feet per mile (0.9 m. per km.), the effective head on the turbines would be, with reservoir full, 776 feet (233 m.). The catchment area above the dam is 474 square miles (1,180 sq. km.). At Waterville the flow of Big Creek, which drains an additional area of 80 square miles (200 sq. km.) is added to the river, and a second dam just below would divert the augmented flow of water into a second pressure pipe, which with a length of 5.2 miles (8.5 km.) would deliver it to turbines at Bluffton under an effective head of 210 feet (63 m.).

This suggested treatment of this stream does not exhaust its power possibilities. In the five-mile (8 km.) stretch immediately above the project as outlined, the fall of the river is 200 feet (60 m.), so that in a total distance of about 22 miles (36 km.) above Bluffton the river experiences a total drop of 1,320 feet (400 m.). But it is believed that this treatment would yield power at very nearly the minimum cost per horsepower.

THE LITTLE TENNESSEE RIVER.

The only site for power development on the lower reaches of this important river is located 2.5 miles (6 km.) northwest of McGhee station, on the Louisville and Nashville Railroad. The permissible height of dam No. 15 is limited by the railroad crossing at McGhee to 30 feet (9 m.). The dam would require but 36,000 cubic yards (27,000 cu. m.) of concrete in its construction; and while but little storage would be afforded at the site itself, the plant would profit immensely from the enormous storage which will be developed higher on the river by the Aluminum Company of America. The plant would have the benefit of a

run-off about 80 percent regulated. The drainage area at the site is 2,456 square miles (6,150 sq. km.).

TELLICO RIVER AND ABRAM'S CREEK.

Between site No. 15 and Alcoa two tributaries reach the Little Tennessee River, each capable of yielding power worthy of consideration.

The more important is Abram's Creek, which empties into the river some five miles below Alcoa. Although this is a small stream, its topography lends itself to a remarkable degree to water-power development. The tributary brooks, rising on the heavily wooded mountain sides, drop sharply to a beautiful cove (or "park," as it would be called out West). At the outlet of this cove the mountains draw closely together, and here a dam 65 feet (20 m.) high and requiring but 28,000 cubic yards (21,000 cu. m.) of concrete would create a storage of some 33,000 acre-feet (40,000,000 cu. m.), covering 1,500 acres (6 sq. km.) of land. The drainage area at the dam is 39 square miles (100 sq. km.); and a regulated flow of 105 second-feet (3 cu. m./sec.) for 24 hours per day throughout the average year would be assured. The treatment of this project is shown on the map (Fig. 3) and profile (Fig. 4). From the dam a 3-mile (5 km.) pipe line to the mouth of Rabbit Creek would afford a net head of 385 feet (115 m.) with reservoir full, and a mean head of 370 feet (111 m.). Below Rabbit Creek, a diversion dam would again divert the water, augmented to 156 second-feet (4.5 cu. m./sec.) for continuous flow, into a steel flume, which in a length of 7 miles (12 km.) terminating at Panther Creek, would accumulate a net head of 450 feet (135 m.). This is an exceedingly attractive power prospect.

TELLICO RIVER.

The location of the town of Tellico Plains, at the head of the beautiful valley called Tellico Plains, precludes the development of a power site the utilization of which would convert the plains into a wonderfully fine reservoir. Ascending from the town of Tellico Plains, the river enters the Unaka Mountain range, and rises rapidly from an elevation of less than 900 feet (270 m.) above sea level to 3,500 feet (1,050 m.) at its source. A standard-gauge logging railroad parallels the stream, and while its location

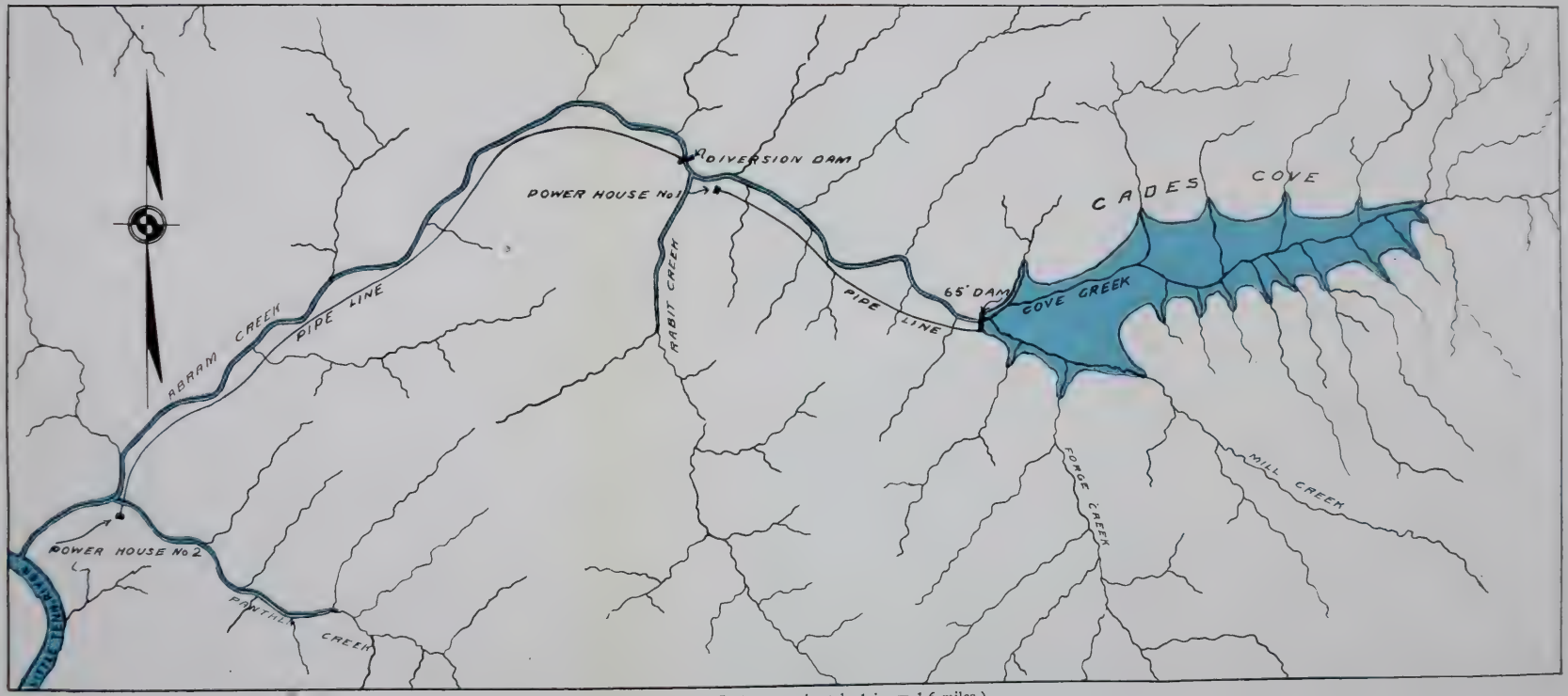


FIG. 3. Map of Abram Creek Project. (Scale approximately 1 in. = 1.6 miles.)

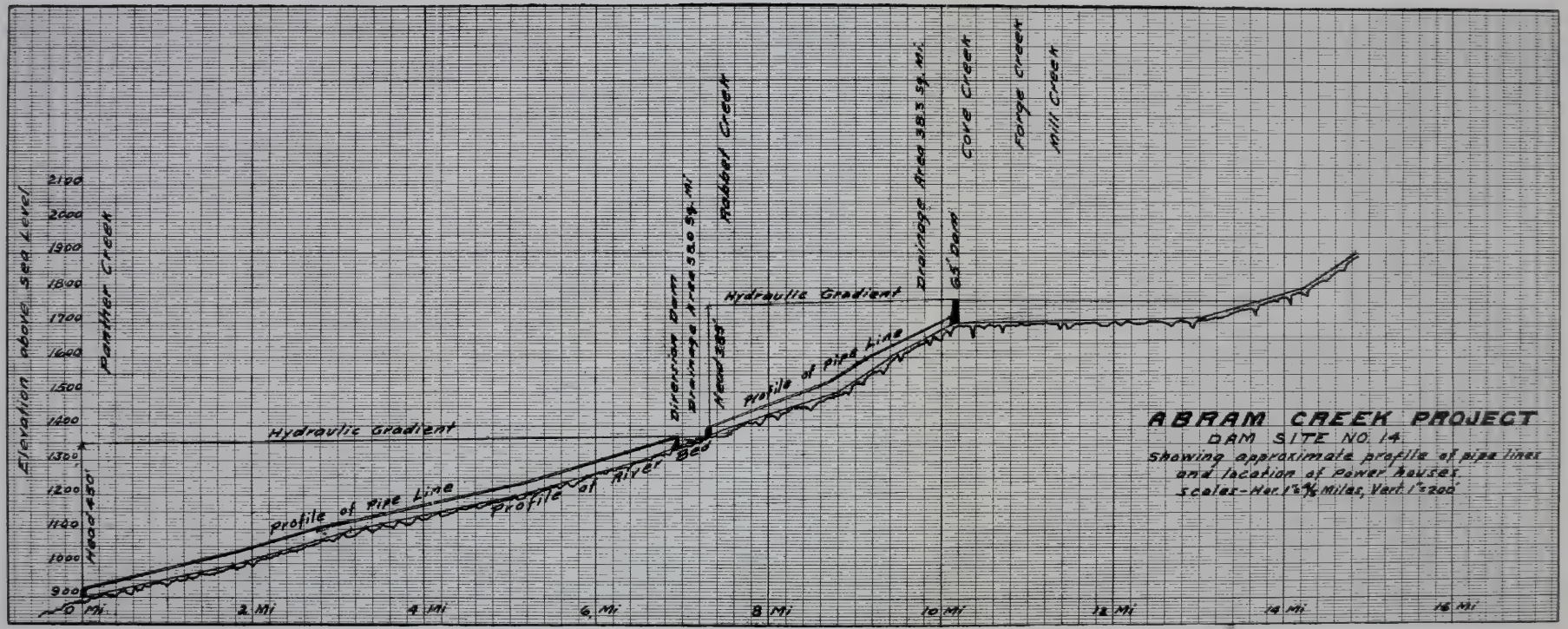


FIG. 4. (One square equals horizontally one-fifth mile, vertically 50 feet.)

there prevents the building of a storage dam, it would facilitate the quick development of a meritorious flume proposition. Such a proposition has received careful engineering study, the result of which shows a feasible development consisting of two plants. The diversion dam for the upper plant would be served by a drainage area of 85 square miles (210 sq. km.). From the dam a flume 23,000 feet (6,900 m.) in length would render available a net head of 175 feet (53 m.). Immediately below the upper power house, a second dam would divert the water from a drainage area increased to 106 square miles (265 sq. km.) into a second flume, which in a length of 7,400 feet (2,220 m.) would yield a net fall of 70 feet (21 m.). Basing power calculations on a stream-flow equal to one-half the mean annual rate of run-off, the 24-hour power yield of the two plants would be 2,750 horsepower. Though this is not a large power output, the development could be quickly made and at a rather low unit cost.

THE HIWASSEE RIVER.

We come finally to the Hiwassee River, a very important power stream, of which the Ocoee is a tributary. Below the mouth of the Ocoee there are two power sites, and above it three. Site No. 18 is situated 4 miles (6.5 km.) above the mouth of the Hiwassee River itself, and No. 17, 16 miles (26 km.) higher, is located near Charleston, Tennessee. Dam No. 18 is limited in height to 25 feet (7.5 m.) by reason of the Southern Railway crossing at Charleston. The dam would require but 20,000 cubic yards (15,000 cu. m.) of concrete, and like dams 4 and 21 on the Clinch River, No. 7 on the Tennessee and Nos. 11 and 12 on the French Broad and No. 15 on the Little Tennessee would doubtless be designed as a movable crest dam. The drainage area is 2,700 square miles (6,500 sq. km.).

Dam No. 17 is limited in height to 45 feet (13.5 km.) by the location of the Louisville & Nashville Railroad as it crosses the Hiwassee River below the mouth of the Ocoee. Water would be backed up under the bridge, and to a considerable distance beyond it on both the Hiwassee itself and the Ocoee. The head of slack-water on the Ocoee would in fact be located only about two miles (3 km.) below the Parksville dam. The drainage area at dam No. 17 is 2,205 square miles (5,500 sq. km.).

Dams No. 19 and No. 20, on the upper Hiwassee, cover the section of the river from the Tennessee-North Carolina State line to Murphy, North Carolina. Together they constitute the project of the Hiwassee Power Company. This project was fully reported upon for the company by Chas. O. Lenz, of New York, in 1914. The holdings and rights of this company are in conflict with those claimed by another concern, The Carolina-Tennessee Power Company, and the matter is at present in litigation between them. The drainage area at Site No. 20 is 1,050 square miles (2,600 sq. km.), and at No. 19, 950 square miles (2,400 sq. km.). Dam No. 20 is 110 feet (33 m.) high and dam No. 19, 143 feet (43 m.). Dam No. 19 is located at the head of slack-water from dam No. 20, and will itself back water nearly to Murphy, North Carolina.

These are both attractive power propositions and but for the legal complications due to rival claims would doubtless have been developed long since.

More attractive than either of these, however, is a possible project located just below dam No. 20. The Louisville & Nashville Railroad from Knoxville to Atlanta enters the gorge of the Hiwassee River near Wetmore, at the point where the river emerges from the Unaka Mountains, here the principal range of the Appalachians. For a distance of nearly 16 miles (26 km.) it clings to the water's edge, reaching at Appalachia Station an elevation of about 1,200 feet (360 m.). Here the railroad begins to climb away from the river's edge, and after making a sensational loop, gains the plateau and turns sharply away from the river. A short distance above Appalachia Station there is a favorable site for a 50-foot (15 m.) dam (dam No. 22), which would back water to the toe of dam No. 20. From this dam a pipe line would lead off down the river. With a length of 3 miles (5 km.), a net head of 190 feet (57 m.) would accrue, while with a length of 7 miles (11 km.) a head of 360 feet (108 m.) net would be available. With a drainage area of 1,080 square miles (2,700 sq. km.) the mean annual run-off is approximately 2,800 second-feet (80 cu. m./sec.); and whether the upper developments be made or not, this is one of the most attractive among the galaxy of tempting water power prospects which have now been spread before you.

In the foregoing summary of the practical undeveloped water power projects in Tennessee, estimates of the horse power were purposely omitted. Yet the first question asked as to a water power project is always: "How much horsepower?"

This question, while apparently the easiest, is in reality the most difficult to answer. The formula for horsepower is quite simple.

$$H.P. = \frac{Q \times H \times e}{8.8}$$

In this formula, for e substitute the efficiency of the plant, for H the head, in feet, and for Q the discharge of the turbines, in cubic feet per second.

For the purpose of preliminary calculation, the value of e may be taken at 80 per cent. If high-grade engineering skill be used in designing the installation, and technical ability in selecting the turbines, this figure may be exceeded. For the value of H, the reconnaissance surveys have established tentative values sufficiently close.

But the selection of the proper value for Q is a matter of no little difficulty.

To begin with, unless daily observations of stream-flow have actually been made at the proposed site covering a long period of years, the hydrograph of the stream at the point cannot be known with detailed precision; and unless this be known, an element of uncertainty (more or less vital, as circumstances determine) necessarily inheres. Seldom is this uncertainty absent from water power calculations.

In the second place, the value of Q proper to use in any given case is a function of many variables. Are we "conservative" only if we base our calculations on the absolute minimum stream-flow on record? Or shall we use "the mean monthly minimum for the average year?" Or again (as is customary with the United States Geological Survey in making estimates of water power), the minimum flow for the six high-water months?" Or the mean annual run-off, or some other figure still? The answer depends on many considerations: on the probable load-factor of the plant, on the cost of coal (and so of auxiliary steam power), on the amount of storage at the proposed plant, on the amount

of storage at other and tributary developments, on the ratio between cost of dam and cost of power generating equipment, and upon other factors which no doubt suggest themselves to members of the Society.

In asking your attention to a discussion of this question, the risk is run of rendering this paper dry. And to write a dry paper on a subject pertaining to water would assuredly be in poor taste. But if the figures with which this paper will close are to inspire the respect for the undeveloped water powers of Tennessee which first-hand acquaintance itself would surely engender, your confidence in their reliability must be secured.

LOAD FACTOR OF WATER-POWER PLANTS.

The consideration of the effect of probable load factor is relatively simple. Load factor is defined as the ratio of the average load which a plant must carry to the maximum load which it may be called upon to meet. There is a daily load-factor, a monthly load-factor and a load-factor for the year. If a water power plant operates as a public utility, the load-factor will be relatively low. If the plant furnishes power exclusively for an electrochemical operation, it will be high. The assumption is sometimes made that for an electrochemical industry the load-factor is 100 percent, that is, that the load never fluctuates but that for 24 hours a day and for 365 days a year the demand for power is constant. This condition is seldom realized, though frequently approximated.

A table giving the power output statistics of all the large power companies of the country for the years 1915, 1916 and 1917, which appeared in the Electrical World for March 23, 1918, shows that the average of the load-factors of 44 leading companies for the year 1917 was 56.1 percent. The highest was that of the Ontario Power Company, 91.5 percent; the lowest that of the Potomac Power Company, 36.09 percent. The load-factor realized by the Tennessee Power Company, 73.41 percent, was high for a public utility because of the large fraction of its power output which was consumed in the electric furnaces of the Aluminum Company of America at Maryville, to whom a large block of power was sold.

Now, other things being equal, the power-generating capacity proper to a given water power development will vary inversely as

the probable load-factor. So a water power prospect that is good for say 10,000 horsepower on the basis of 100 percent load-factor is a 20,000-horsepower project for a 50 percent load-factor. But this is only one consideration.

Enough has already been said to indicate the truth, familiar enough to all water power engineers, that any given water power prospect can be properly evaluated only by a study of the individual proposition with respect to the use which is to be made of the power output, together with all the other variables which affect it.

Obviously, therefore, no categorical figure can possibly be named as the plant capacity when referring to any water power prospect, unless and until such detailed study has been devoted to it. And yet I am under the somewhat painful necessity of ascribing tentative values as the economic capacities of the latent water powers of Tennessee. In seeking for such values one may well be guided by the experience of going water power concerns. However one approach the task, there are certain outstanding principles to be kept in mind. Even for a 100 percent power-factor electrochemical utilization, the development of only so much power as the extreme minimum stream-flow will yield violates the most fundamental principle of conservation. Again, the "average monthly minimum run-off" is too low a figure on which to base calculations, and the "minimum flow for the six high-water months" quite frequently is. In most electrochemical plants, the power-consuming devices, whether electric furnace, electrolytic cell or what not, are engaged either singly or in groups in such manner as to constitute units of productive equipment. To elucidate the argument to which I should like to call your attention, please consider the case of a suppositious plant. The power-consuming equipment, let us say, is to consist of electric furnaces, each requiring for its operation 10,000 horsepower, and for production must be run continuously for a two-weeks' period, or not at all. A year would then consist of 26 furnace-time-units. The generating equipment at the water power plant will consist of a certain number of units of 10,000 horsepower net output capacity (measured at the furnace terminals). The study of the hydrograph of the stream has yielded the following information, which for brevity can best be arranged in tabular form.

Horsepower	No. of Furnace-time-units for which Power is Available
50,000	26
60,000	25
70,000	23
80,000	20
90,000	16
100,000	13

According to this table, 50,000 horsepower is available for 26 furnace-time-units, or for the entire year, 60,000 for 25 units, or all but two weeks in the year, and so on down to 100,000 horsepower which is available for twenty-six out of the fifty-two weeks in the year. Now, if the suppositious plant is still only a "prospect," how big a water power prospect is it? A 50,000 horsepower project? Clearly, no. A 60,000? An 80,000? A 100,000?

Stated in this manner, the problem is a perfectly obvious one. The answer, however, can be furnished only when we know the following factors: the capacity cost of equipment per productive unit; the appropriate interest and depreciation charge to apply to the same; the type of market for the finished output, and the profit per pound, or per productive unit, per productive time-unit on such output. With this information actually in hand, a simple equation could be written, the solution of which would give the answer.

That size of power-generating equipment is the most advantageous to install which will guarantee the largest money return per dollar of investment to be made. If the market for the product of the proposed industry is both good and certain, and the margin of profit per pound on the output is adequate, then considerably more power-generating equipment should be installed than would be required to utilize the minimum flow of the stream. In other words, if for example the profit on six months' use of equipment will more than provide for the annual interest and depreciation charge thereon, it pays to install equipment which will of necessity stand idle for half the year.

Most of you will agree with the opinion that the answer in the case of our suppositious plant would be nearer 100,000 than 50,000 horsepower. It might easily run to a higher figure still.

To the above argument add the consideration of the utilization in connection with the water power of auxiliary steam power,

and at once the problem becomes more complex, and usually the answer (in horsepower) is a still larger figure.

Beyond question, as relations now exist, the economic maximum of water power development at a given site is had by the utilization of steam auxiliary in connection therewith. To illustrate this point the experience of a few typical large water power companies for the year 1917 may be cited.

Here is a table showing the total power output of twelve such companies, the output of their auxiliary steam plants, and the percentage of the total output which was generated by steam. In the case of the Tennessee Power Company this percentage was 15.5 for the year 1917, and for the 12 plants the average was 22 percent.

TABLE I.

Company	Total Output Kilowatt-hours	Generated by Steam Kilowatt-hours	Percent of Output from Steam
Pacific Gas & Electric Co.	854,099,000	195,000,000	22.9
Tennessee Power Company	547,945,475	84,000,000	15.5
Electric Company of Mo.	376,891,756	112,000,000	29.7
Alabama Power Company	289,715,125	41,000,000	14.1
Georgia Railway & Power Co.	258,607,882	22,000,000	8.5
Southern California Edison Co.	794,687,405	144,000,000	18.2
Portland Railway & Light Co.	218,086,315	23,000,000	10.5
Adirondack Electric Railway Co.	158,570,164	51,000,000	32.1
Rochester Railway & Light Co.	162,490,264	51,000,000	31.4
New England Power Company	200,600,000	54,000,000	18.0
Wisconsin Edison Company	275,966,740	77,000,000	28.0
Minneapolis General Electric Co.	222,146,210	75,000,000	33.7

(*Electrical World*, March 23, 1918.)

Recently the author had occasion to make an inventory of the power developments of the Appalachian South, and found that the total of installed capacity in water wheels which will be in actual commission before the end of 1918 is approximately 860,000 horsepower. And in conjunction therewith, the combined steam auxiliary power foots up to 210,000 horsepower, or approximately 25 percent of the water power to which it is auxiliary.

In a few instances among the undeveloped projects which are briefly described in this paper, the dams would create storage capacity large enough to render the entire run-off of the river available for power generation at a uniform rate throughout the

year. And in such cases auxiliary power loses all interest. But this is exceptional; and the contiguity of the enormous coal deposits of Tennessee to the water power sites is a factor of much importance in connection therewith.

To return to the consideration of plant capacity and its relation to stream-flow, let us examine current practice among going water power developments, taking again a few typical examples for analysis.

Beginning nearest home, consider the case of the two Ocoee River plants of the Tennessee Power Company.

At Parksville, a dam 110 feet (33 m.) high is built, back of which there lies a drainage area of 602 square miles (1,500 sq. km.). The power-generating equipment at Parksville consists of five 5,000-horsepower units. Assuming 85 percent plant efficiency, there is required for the generation of 25,000 horsepower under a head of 105 feet (31.5 m.) a discharge of 2,460 second-feet (70 cu. m./sec.). And this flow coming from a drainage basin of 602 square miles (1,500 sq. km.) in extent calls for a yield of 4.1 second-feet per square mile (0.045 cu. m./sec./sq. km.). Now this flow is greater than the mean annual runoff; it is greater even than the mean run-off of the wettest year on record at Parksville. In fact, during the 57 months beginning with January, 1911, and terminating with September, 1915, the monthly mean run-off exceeded 2,460 second-feet (70 cu. m./sec.) during only seven of the 57 months. (U. S. S. Water Supply, Paper 403, p. 169.).

Roughly speaking, therefore, water enough to operate the plant at its rated capacity was available for only about 12 percent of the time. Had the plant capacity at Parksville been posited upon the minimum recorded run-off for any single day, the wheel capacity, instead of being 25,000 horsepower would have been 1,800 horsepower! Had it been designed on the basis of the minimum monthly flow, it would have been 5,000 horsepower. Finally, had the capacity been calculated to utilize the mean annual run-off (as deduced from the records of 1911-1915 inclusive), the capacity would have been 17,000 horsepower. Now in spite of these figures, and of the further fact that but little storage is afforded at the Parksville dam, and little, if any, tributary storage is likely to be provided in the future,

this water power is not over-developed. That is to say, the returns upon the investment represented by the last of the five units are sufficient to justify its installation.

On the upper development on the Ocoee, called the Caney Creek plant, the installation consists of 2 units each of 10,000 horsepower capacity. Operating under a head of 260 feet (78 m.), the generation of 20,000 horsepower requires (at 85 percent efficiency) a flow of 800 second-feet (23 cu. m./sec.), and coming from a catchment basin covering 515 square miles (1,300 sq. km.), this signifies a yield of 1.55 second-feet per square mile (0.0177 cu. m./sec./sq. km.). While this figure is exceeded by the mean annual run-off (2.24 second-feet per square mile (0.0256 cu. m./sec./sq. km.) at Copper Hill), it is greater than the average of the minimum monthly flow (1.12 second-feet per square mile = 0.0128 cu. m./sec./sq. km.). The mean monthly flow of the Ocoee has equalled 1.55 second-feet per square mile (0.0177 cu. m./sec./sq. km.) during 32 of the 57 months cited. But the Caney Creek plant has no storage whatever, and the plant could have been operated at full capacity for but 731 days out of the 1,460 days between October 1, 1911, and October 1, 1915, or for exactly 50 percent of these days. Many of these 731 days were isolated days. For 189 days, or for about 13 percent of the time the stream-flow was insufficient to operate even one of the two units to full capacity. Yet the flume was built with capacity to carry 1,200 second-feet (35 cu. m./sec.), or enough water to operate a third unit, should one be installed in the future.

There may be those who, having followed the argument thus far, will say "In spite of your statement to the contrary, the figures you present do convict these two plants of over-development." In order to counter such a charge, Table II has been prepared, in which is presented the results of an analysis of a dozen going water power concerns taken mostly from the Southern Appalachian section. It is not at all a sectional matter, and current practice is not essentially different elsewhere.

In this table the discharge in cubic feet per second requisite to operate the plants at rated capacity is calculated on the uniform basis of a plant efficiency of 85 percent. Thence is deduced the requisite discharge in terms of run-off per square mile of catchment basin. For comparison with this figure is presented the

TABLE II.

Showing Relation of Installed Capacities to Stream Flow in Typical Hydro-electric Developments.

Power Company	Name of Site	Installed Capacity. Horsepower.	Head. Feet.	Discharge requisite at 85% efficiency to yield rated horsepower. Cu. ft. per second.	Drainage area at site. Square miles.	Requisite discharge to yield rated horsepower. Cu. ft. per second per sq. mi.	Mean monthly minimum flow available. Cu. ft. per second per sq. mi.	Mean annual flow available. Cu. ft. per second per sq. mi.	Percentage of mean annual flow required by plant at rated capacity.
Mohawk Hydroelectric Co.....	Saroga Creek, Ephrata, N. Y...	6,700	300	230	56	4.12	0.35	1.50	272
Tennessee Power Co.....	Parksville	25,000	105	2,460	602	4.10	1.12	2.24	183
Tennessee Power Co.....	Caney Creek	10,000	260	800	515	1.55	1.12	2.24	70
Southern Power Co.....	Great Falls	32,100	72	4,630	4,200	1.10	0.60	1.80	61
Southern Power Co.....	Rocky Creek	32,100	63	5,270	4,475	1.18	0.60	1.80	66
Southern Power Co.....	Ninety-nine Island	24,200	72	3,480	1,545	2.18	0.60	1.80	121
Southern Power Co.....	Fishing Creek	44,000	50	9,300	4,000	2.32	0.60	1.80	129
Georgia Railway & Power Co..	Tallulah Falls	95,000	606	1,620	191	8.50	0.73	2.70	314
Tennesse Eastern Electric Co..	Greenville	13,400	68	2,040	1,140	1.78	0.60	2.10	85
Central Georgia Power Co.....	Lloyds Shoals	16,200	103	1,630	1,350	1.21	0.55	1.80	67
Watauga Power Co.....	Watauga River, Tenn.....	4,800	55	910	406	2.23	0.52	1.90	117
Alabama Power Co.....	Lock 12, Coosa River.....	105,000	68	16,000	*7500	2.13	0.52	1.66	128
United States Government.....	Muscle Shoals	160,000	90	18,400	30,800	0.60	0.44	1.66	36
Tallassee Power Co.....	Yadkin River, Badin, N. C.....	127,000	165–180	7,500	3,938	1.90	0.73	1.70	112
Knoxville Power Co.....	Little Tenn. River, Cheoah Site	96,000	200	5,000	1,840	2.73	1.12	2.70	101

* Approximated.

mean monthly minimum flow at each site and the mean annual flow, expressed in cubic feet per second per square mile. And finally, in the last column is shown the percent of the mean annual rate of run-off which is required to operate the plant at rated capacity. From this column it is apparent the practice of the Tennessee Power Company is by no means extreme.

The case of the famous Tallulah Falls development of the Georgia Railway & Power Company is interesting. Here the installed capacity is 95,000 horsepower. The mean annual power available is about 200,000,000 kilowatt hours, or 269,000,000 horsepower hours. If this were furnished at 100 percent load factor, it would yield an output of 30,600 horsepower. Yet by the aid of auxiliary steam power, the company last year was enabled to dispose of 260,000,000 kilowatt hours of power. The present development compasses a storage of about 31,100 acre-feet (40,000,000 cu. m.), and a second reservoir now under construction will increase the storage to 146,000 acre-feet (182,000,000 cu. m.). This storage would afford 21,000 horsepower continuously for 200 days. The mean monthly minimum flow without storage would afford approximately but 8,000 horsepower. To generate the full 95,000 horsepower of installed capacity continuously would require more than three times the water which the river yields.

Scanning this table, one may be led to conclude that all the operations selected for tabulation (the selections were made absolutely at random) are public service operations, and that therefore no conclusions may be deduced from such a study that can bear upon the electrochemical industries. But such is not the case. The first twelve operations are such, however, and on the average, they would require for continuous operation at full rating 135 percent of the mean annual flow of the respective streams.

The thirteenth plant in the table is the Muscle Shoals development, soon to be undertaken by the United States Government, to furnish power for nitrogen fixation. At Muscle Shoals the Government will build a dam 103 feet (31 m.) high, which will render a head of 90 feet (27 m.) available. The power equipment will have a capacity of 160,000 horsepower. This calls for a yield of 0.60 cubic feet per second per square mile (0.007 cu. m./sec./sq. km.) of drainage basin. While this is but 36 percent

of the mean annual yield (and therefore the development, by comparison, is seen to be certainly very conservative), it is nevertheless greater by about 37 percent than the mean monthly minimum flow. It is, moreover, 240 percent greater than the recorded minimum monthly flow (0.25 second-feet per square mile (0.003 cu. m./sec./sq. km.) in October, 1905). (Water Supply, Paper 353, p. 192.)

During the period from January 1, 1895, to January 1, 1914, the flow at Muscle Shoals has been less than 18,400 second-feet (523 cu. m./sec.) during approximately 1,650 days, or for just about 24 percent of the time. There will be no storage at Muscle Shoals. Hence, if 160,000 horsepower is to be available for a 100 percent load factor operation, auxiliary power to the extent of at least 93,000 horsepower must be provided, and this steam plant must furnish some part of the power for 24 percent of the time.

Returning to the consideration of Table II, the last two plants cited are those of the Tallassee Power Company at Badin, North Carolina, and the Knoxville Power Company on the Little Tennessee River at the mouth of the Cheoah River. These are not public service operations, but electrochemical, for the Tallassee Power Company and the Knoxville Power Company are camouflage names for the Aluminum Company of America. At Badin three units each of 24,000 kilowatt capacity are now installed and in operation, and a fourth unit is to be installed. The writer is not advised as to the amount of storage available at this plant, but it is understood not to be very considerable. The requirement for water at this plant appears to be about 12 percent more than the entire mean annual run-off of the river. Who shall say that this development is not in accordance with good engineering practice?

The Cheoah site you yourselves visited this morning. As you saw, three 24,000 horsepower units are in process of being installed. The fourth unit, bringing the plant capacity to 96,000 horsepower, will not be placed until some of the tributary storage is developed. The table shows that in order to operate this plant at rated capacity with load-factor equal to 100 percent, the entire run-off must be conserved, or, in other words, enough storage must be provided to effect 100 percent stream regulation. Since

this statement applies to the average year, it would be necessary to carry water over from the wet year to the dry. However, even were this condition never to be realized, the installation would be conservative, for considerable steam auxiliary power will be provided. To operate the 3 units, a yield of 3,750 second-feet (107 cu. m./sec.) is required, and to operate 4, 5,000 second-feet (142 cu. m./sec.). An inspection of the duration curves plotted upon the hydrographs of the Little Tennessee at the Cheoah site (Figs. 5 to 12 inclusive[3]) shows that for the years 1907 to 1914 inclusive the plant could have operated without any storage at the various percentages of full rating (96,000 horse-power) shown in the tabulation (Table III) for the various percentages of time set opposite each percentage of rating.

TABLE III.

Showing Percentage of Rating at Which the Cheoah Development Could Operate for Corresponding Percentages of Time, Without Storage.

Percentage of Rating	Horsepower Output	Percentage of Time During								Average Year
		1907	1908	1909	1910	1911	1912	1913	1914	
100	96,000	29	33	51	25	19	37	26	16	30
80	77,000	50	52	65	40	29	50	39	27	44
60	57,500	70	63	71	63	52	64	52	40	60
40	38,200	93	83	90	82	83	90	84	64	84

The table shows the plant could operate at full rating without storage for but 30 percent of the time during the year of average stream-flow.

Now citations such as have been brought to your attention could be indefinitely multiplied; but evidence enough has surely been adduced to show that water power calculations, even for electrochemical utilization, are not based in ordinary practice upon minimum stream-flow.

In this presentation of the undeveloped water powers of Tennessee, the basis for calculation of the economic capacity of each of the power prospects is the following: If the project provides

[3] Only Fig. 12 has been reproduced for the Transactions. A copy of the paper containing the remaining seven hydrographs may be obtained by application to the author, at Knoxville, Tenn., or to the Tennessee State Geological Survey, at Nashville.

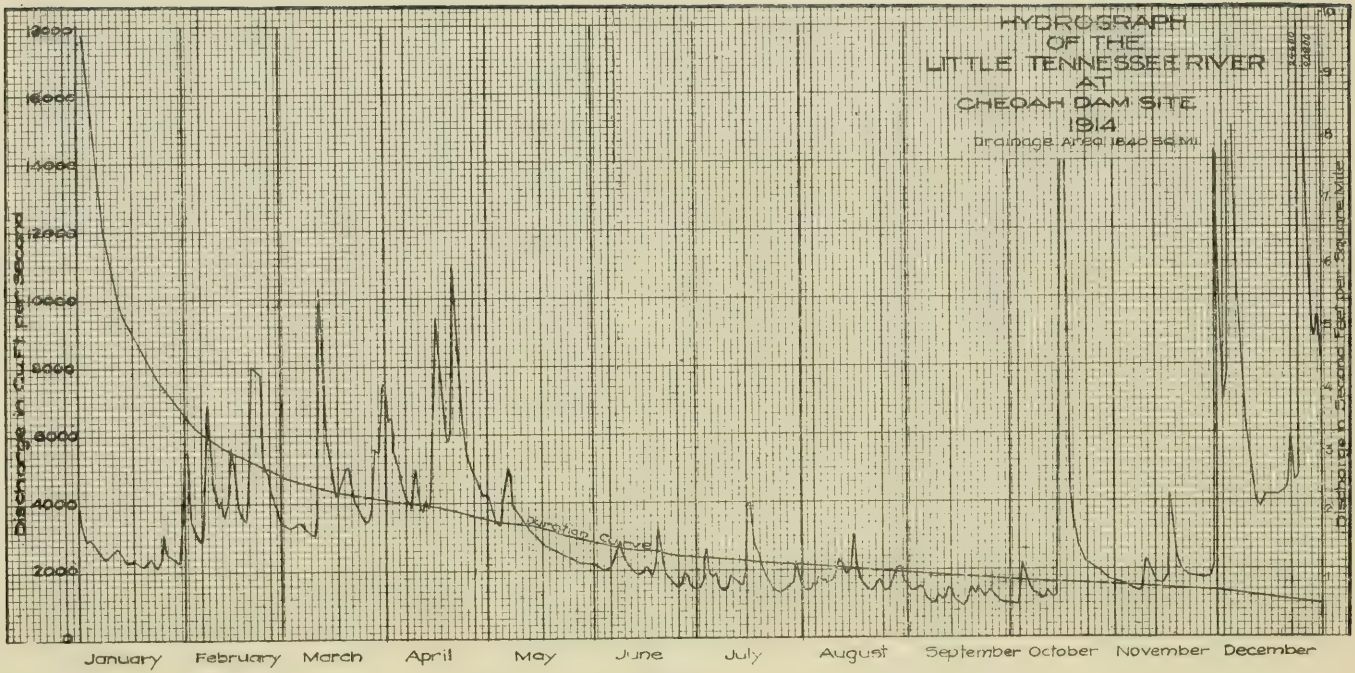

HYDROGRAPH
OF THE
LITTLE TENNESSEE RIVER
AT
CHEOAH DAM SITE.
1914
Drainage Area 1640 Sq. Mi.
Discharge in Cu. Ft. per Second
Discharge in Second Feet per Square Mile
Duration Curve
January
February
March
April
May
June
July
August
September
October
November
December

FIG. 12.

storage capacity enough to completely regulate the run-off at the site, the calculation is based on the mean annual rate of flow, in arriving at the proper figure for electrochemical utilization. If no storage whatever is afforded, the basis is one-half of the mean annual rate. And if the project permits of limited storage, the basis is the mean annual rate of run-off multiplied by a factor lying between one-half and unity, and determined in value by the extent of storage which the project will actually afford.

In Table VII, with which this paper concludes, is presented in summarized form all the essential water power data pertaining to the power sites herein described. Columns 26 and 27 show the economic capacity at each site, deduced as just explained; the figure in column 26 being that which applies if no upper and contributory storage be developed, and that in column 27, the figure if the storage at upper sites herein contemplated be also developed. To illustrate the meaning of column 27, reference to site No. 3, on the Clinch River may be made. The development at this site would benefit from the storage effected at site No. 1, on the Powell River, and that at site No. 2, on the Clinch; and the effect of this upper storage would be to increase the economic plant capacity at site No. 3 from 74,000 to 87,000 horsepower.

Columns 28 and 29 in Table VII present what is called the economic plant capacity for diversified utilization. The figures for this horsepower are deduced from those for electrochemical utilization simply by the process of increasing these latter uniformly by 50 percent. All of these horsepower calculations are made upon the basis of a plant efficiency of 80 percent.

Now it will readily be conceded that preliminary estimates of water power are necessarily tentative, and if you have closely followed the line of reasoning which has led to the adoption of the figures presented in this paper, we feel confident that you will grant we have steered a safe course between the Scylla of underestimation and the Charybdis of even slight exaggeration.

Column 3 of Table VII shows the drainage area tributary to each site. To obtain this area a large topographic map of the entire region covered by the survey was made by mounting together the topographic sheets issued by the U. S. Geological Survey. On this map the location of the boundaries of all drainage areas was drawn by the aid of the contour lines, and the drainage areas were then measured by use of the planimeter.

Columns 4 to 9, inclusive, present the run-off data. The source of this data is the annual series of Water Supply Papers of the United States Geological Survey, entitled "Surface Water Supply of the United States," covering the years 1902-1916 inclusive, also Bulletins No. 8 and No. 20 of the North Carolina Geological and Economic Survey, entitled "Water Powers of North Carolina," Water Supply Paper No. 197 of the United States Geological Survey, entitled "Water Resources of Georgia," and Bulletin No. 17 of the Alabama State Geological Survey, entitled "Water Powers of Alabama."

For some years gauging stations have been maintained by the United States Geological Survey upon most of the rivers of the region. The data thus obtained, and reported in the bulletins noted above, has been collated by the author, and in condensed form is here presented. Table IV gives the mean annual run-off, expressed in cubic feet per second per square mile of drainage area; Table V gives the minimum monthly discharge, and Table VI the minimum flow for any day on record, similarly expressed. The tables give this data as completely as it is known for all the stations where consecutive observations have been made within the region for more than one or two years. The data is comprised in columns 1 to 13 inclusive; and in column 14 is given for comparison the run-off at Florence, Ala., which is located on the Tennessee River, close to Muscle Shoals. In column 15 is shown the mean values of the run-off for stations 1 to 13 inclusive. These data are unfortunately not of uniform reliability. Thus, it may be stated that the values given in columns 7, 8, 9 and 10 for the Tuckaseegee, the Little Tennessee and the Ocoee Rivers have received very close engineering study, have been independently checked, and have been found to be highly reliable. On the other hand, that in columns 1 and 2, for stations on the Holston River, has not received such independent checking; and the values in these columns are so at variance with the rest of the data presented, and moreover with the rainfall data (which is summarized and graphically presented in the chart of mean annual rainfall of the United States, Fig. 13), that less weight can be ascribed to them in arriving at average values needful for the water power calculations than would otherwise be the case. No observations whatever have been made on the Clinch or the Powell River; and in assuming values for the run-off of these two rivers,

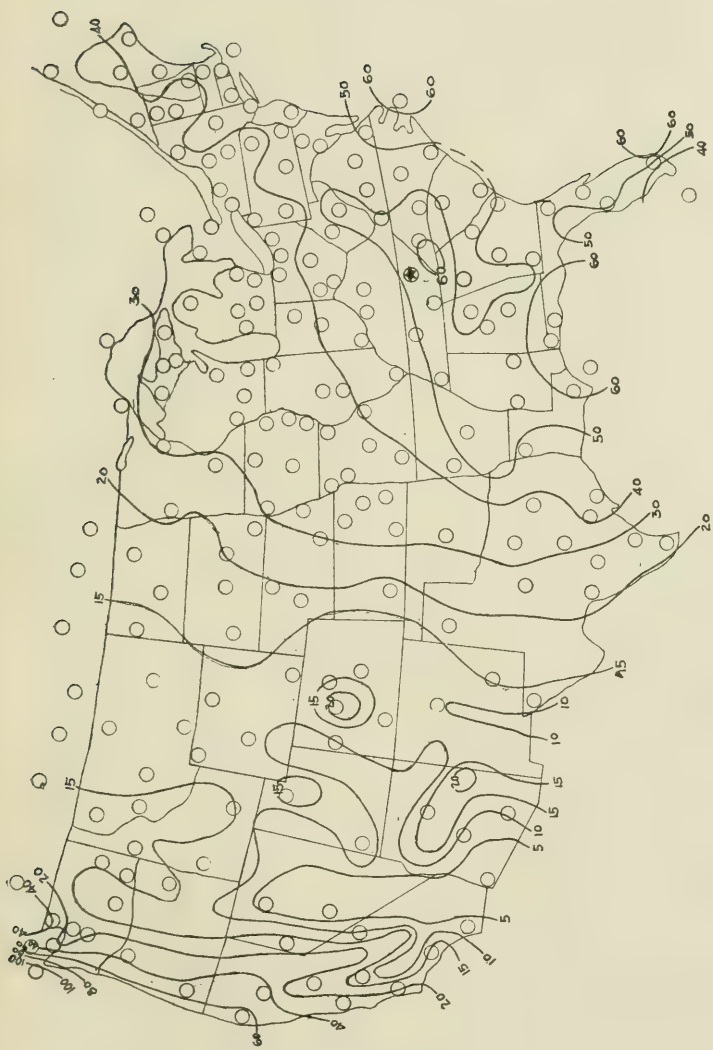


FIG. 13.

Table IV.

Mean Annual Run-off. Cubic Feet per Second per Square Mile.

River	Holston	Holston	Nolichucky	Pigeon	French Broad	Tenn.	Tuckaseegee	Little Tenn.	Little Tenn.	Ocoee	Hiwassee	Hiwassee	Tenn.	Tenn.	Mean for Stations 3-13 inclusive
Station	Bluff City	Austin Mills	Greenville	Newport	Asheville	Knoxville	Bryson	Judson	McGhee	Copper Hill	Murphy	Reliance	Chattanooga	Florence	
Drainage Area	828	3060	1099	655	987	8990	662	675	2470	374	410	1180	21400	30800	
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year															
1902	1.91	.....	.....	.....	.....	1.62	2.57	3.14	.....	.....	2.27	2.14	1.74	1.86	2.24
1903	1.48	.....	.....	.....	.....	1.62	2.78	3.63	.....	.....	2.72	2.55	1.85	1.98	2.52
1904	0.86	0.87	1.03	1.07	.....	0.84	1.47	1.65	.....	1.31	1.29	1.20	1.00	0.92	1.21
1905	1.27	1.29	1.60	1.65	2.22	1.35	2.16	2.64	2.19	1.81	2.10	1.91	1.54	1.38	1.92
1906	1.52	1.59	2.43	.....	3.94	1.94	3.37	4.86	3.38	3.29	3.43	3.18	2.10	1.60	3.19
1907	1.93	1.69	1.50	1.65	1.64	1.52	2.18	2.70	2.34	2.20	2.67	2.27	1.77	1.85	2.04
1908	1.81	1.77	2.05	2.09	2.46	1.72	2.50	3.39	.....	2.41	2.65	2.29	1.84	1.66	2.34
1909	1.46	1.59	.....	2.59	2.75	1.73	3.20	4.02	3.27	2.87	3.41	3.12	2.27	2.19	2.92
1910	1.06	1.08	.....	.....	1.98	.....	2.11	2.44	2.21	.....	2.01	2.13	1.36	1.30	2.03
1911	1.52	1.29	.....	.....	1.55	.....	2.19	3.13	2.21	1.90	1.96	1.79	1.61	1.52	2.04
1912	1.65	1.41	.....	.....	2.13	.....	2.70	.....	2.86	2.75	2.63	2.37	1.87	2.18	2.47
1913	1.44	0.98	.....	.....	2.11	.....	2.49	.....	2.58	2.49	2.14	.....	1.68	1.75	2.25
1914	1.24	1.15	.....	.....	2.91	.....	2.33	2.50	.....	1.24	1.92	.....	.....	1.48	2.18
Average	1.47	1.34			2.37		2.46	3.10	2.64	2.24	2.40	2.26	1.72	1.67	2.24

TABLE V.

Minimum Monthly Discharge. Cubic Feet per Second per Square Mile.

River	Holston	Holston	Nolichucky	Pigeon	French Broad	Tenn.	Tuckaseegee	Little Tenn.	Little Tenn.	Ocoee	Hiwassee	Hiwassee	Tenn.	Tenn.	Mean for Stations 3-13 inclusive
Station	Bluff City	Austin Mills	Greenville	Newport	Asheville	Knoxville	Bryson	Judson	McGhee	Copper Hill	Murphy	Reliance	Chattanooga	Florence	
Drainage Area	828	3060	1099	655	987	8990	662	675	2470	374	410	1180	21400	30800	
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year															
1902	0.42	.....	.....	.....	.....	0.60	0.71	0.93	.....	.....	0.57	0.74	0.51	0.42	0.67
1903	0.25	.....	.....	.....	.....	0.31	0.71	0.68	.....	.....	0.68	0.67	0.33	0.39	0.56
1904	0.22	0.21	0.34	0.28	.....	0.22	0.58	0.44	.....	0.61	0.43	0.35	0.26	0.31	0.40
1905	0.31	0.32	0.55	0.56	0.88	0.38	0.85	0.89	0.73	0.92	0.77	0.68	0.48	0.25	0.77
1906	0.69	0.87	1.65	.....	2.04	1.40	1.96	2.44	1.94	2.28	1.83	1.64	1.34	0.44	1.85
1907	0.98	0.79	0.85	0.48	0.56	0.68	1.19	1.33	1.25	1.40	1.41	1.22	0.77	0.70	1.01
1908	0.44	0.61	0.84	0.88	1.37	0.62	1.18	1.39	.....	1.07	0.98	0.85	0.72	0.60	0.99
1909	0.31	0.38	.....	0.82	1.20	0.33	1.15	1.21	1.03	1.05	0.96	0.88	0.53	0.42	0.92
1910	0.37	0.48	.....	.....	1.03	.....	0.92	0.95	0.82	.....	0.80	0.80	0.39	0.43	0.81
1911	0.41	0.31	.....	.....	0.13	.....	1.06	1.44	1.06	0.88	0.83	0.70	0.60	0.37	0.94
1912	0.43	0.44	.....	.....	1.18	.....	1.11	.....	1.15	1.41	1.08	0.99	0.56	0.65	1.07
1913	0.51	0.42	.....	.....	1.18	.....	1.11	.....	0.89	0.88	0.73	.....	0.42	0.37	0.87
1914	0.55	0.56	.....	.....	1.72	.....	1.23	1.15	.....	0.66	0.80	.....	.....	0.37	1.11
Average	0.45	0.49			1.21		1.06	1.17	1.11	1.12	0.91	0.87	0.58	0.44	0.92

Table VI.

Minimum Flow for Any Single Day on Record. Cubic Feet per Second per Square Mile.

River	Holston	Holston	Nolichucky	Pigeon	French Broad	Tenn.	Tuckaseegee	Little Tenn.	Little Tenn.	Ocoee	Hiwassee	Hiwassee	Tenn.	Tenn.
Station	Bluff City	Austin Mills	Greenville	Newport	Asheville	Knoxville	Bryson	Judson	McGhee	Copper Hill	Murphy	Reliance	Chattanooga	Florence
Drainage Area	828	3060	1099	655	987	8990	662	675	2470	374	410	1180	21400	30800
Year														
1902	0.35	.....	.....	.....	.....	0.46	0.45	0.71	.....	.....	0.24	0.59	0.37	0.36
1903	0.21	.....	.....	.....	.....	0.24	0.57	0.50	.....	.....	0.57	0.50	0.27	0.29
1904	0.18	0.16	0.29	0.21	.....	0.20	0.51	0.41	.....	0.57	0.37	0.32	0.24	0.28
1905	0.28	0.26	0.51	0.46	0.85	0.36	0.76	0.41	0.56	0.79	0.63	0.51	0.40	0.25
1906	0.36	0.56	0.85	.....	1.35	0.73	1.30	1.48	1.30	1.70	0.83	1.06	0.84	0.36
1907	0.71	0.49	0.67	0.46	0.39	0.48	0.83	0.89	0.79	0.96	1.11	0.85	0.56	0.48
1908	0.30	0.37	0.54	0.53	0.80	0.36	0.83	0.89	.....	0.96	0.64	0.58	0.42	0.37
1909	0.22	0.32	.....	0.70	1.02	0.22	0.98	1.07	0.91	0.96	0.85	0.75	0.49	0.34
1910	0.26	0.37	.....	.....	0.93	.....	0.80	0.61	0.67	.....	0.72	0.69	0.38	0.41
1911	0.26	0.17	.....	.....	0.60	.....	0.80	0.86	0.62	0.50	0.50	0.70	0.44	0.31
1912	0.35	0.34	.....	.....	1.11	.....	0.83	.....	0.91	1.04	0.81	0.72	0.44	0.32
1913	0.30	0.28	.....	.....	0.94	.....	0.79	.....	0.67	0.35	0.50	.....	0.33	0.31
1914	0.22	0.22	.....	.....	0.60	.....	0.51	0.56	.....	0.23	0.45	.....	.....	0.29

TABLE VII.

THE LARGER UNDEVELOPED WATER P

DAM NUMBER	NAME OF RIVER	STREAM FLOW							HEIGHT OF DAM FEET	MEAN HEAD ON TURBINES FEET	STORAGE							
		DRAINAGE AREA SQUARE MILES	AVERAGE RUN-OFF FOR YEAR CU FT PER SEC PER SQ MI	MEAN FLOW FOR YEAR CU FT PER SECOND	MONTHLY MINIMUM RUN-OFF AVERAGE YEAR CU FT PER SEC PER SQ MI	MONTHLY MINIMUM FLOW AVERAGE YEAR CU FT PER SECOND	MONTHLY MINIMUM RUN-OFF LOWEST YEAR CU FT PER SEC PER SQ MI	MONTHLY MINIMUM FLOW LOWEST YEAR CU FT PER SECOND			AREA OF POOL ACRES	STORAGE CAPACITY THOUSAND OF ACRES FEET	STORAGE CAPACITY MILLIONS CU FEET	ASSUMED DRAW-DOWN FEET UPPER STORAGE NOT CONSIDERED	ASSUMED DRAW-DOWN THOUSAND OF ACRES FEET UPPER STORAGE NOT CONSIDERED	STORAGE DISCHARGE UPPER STORAGE NOT CONSIDERED CU FEET PER SECOND FOR 24 HOUR SERVICE			UPPER STOR DISCHARG CU FEET PER FOR 24 HOUR SE	
																1 YEAR	6 MONTHS	3 MONTHS	1 YEAR	6 MONTH
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	2
1	POWELL	700	2.00	1400	0.70	490	0.30	210	180	170	31100	1870	82500	50	475	655	1310	2620	—	—
2	CLINCH	1548	2.00	3096	0.70	1080	0.30	465	160	150	27400	1460	63500	60	800	1100	2200	4400	—	—
3	CLINCH	2883	2.00	5766	0.70	2020	0.30	865	175	165	66000	2100	91500	40	700	960	1920	3840	2770	5540
4†	CLINCH	4420	1.95	8640	0.70	3100	0.30	1320	45	40	10900	163	7100	10	8	12	24	48	4000	8000
21†	CLINCH	3551	2.00	7102	0.70	2480	0.30	1060	85	75	24140	681	29600	15	200	225	550	1100	4000	8000
5	HOLSTON	3392	2.00	6784	0.70	2380	0.30	1020	110	100	14500	508	22500	30	200	275	550	1100	—	—
6	HOLSTON	3656	2.00	7312	0.70	2560	0.30	1090	90	80	10750	326	14000	25	160	220	440	880	275	550
7	TENNESSEE	8990	2.00	17980	0.70	6250	0.32	2850	40	37	17900	240	10400	10	100	136	272	544	1290	2580
8	NOLICHUCKY	780	2.10	1620	0.85	664	0.35	274	70	130	350	5	223	20	5	9	18	36	—	—
9	NOLICHUCKY	1342	2.10	2820	0.85	1140	0.35	470	100	90	9800	326	14200	30	250	342	684	1368	9	18
10	NOLICHUCKY	1752	2.10	3680	0.85	1490	0.35	615	70	60	8600	200	8700	20	70	96	192	384	351	702
11	FRENCH BROAD	4455	2.20	9800	0.90	4000	0.40	1780	75	70	10800	270	11700	20	80	110	220	440	942	884
12	FRENCH BROAD	4983	220	10950	0.90	4470	0.40	2000	45	40	14300	215	9350	10	80	110	220	440	1052	2104
13	PIGEON	475* 536*	270	1280 1445	1.10	523 590	0.50	238 268	250	720 210	1540	128	5600	200	100	136	272	544	—	—
14	ABRAM CREEK	39 58*	270	105 156	1.10	43 64	0.50	20 29	65	370 450	1470	33	1440	65	33	45	90	180	—	—
15	LITTLE TENN.	2456	2.60	6400	1.10	2700	0.45	1100	30	27	6880	69	5000	10	30	41	82	164	3000	6000
16	TELLICO	85 106*	2.70	230 287	1.10	93 116	0.50	43 53	Diversion	175 70	NONE	—	—	—	—	—	—	—	—	—
17	HIWASSEE	2205	2.50	5520	0.90	1980	0.45	1000	45	40	16350	245	10650	10	80	110	220	440	87	174
18	HIWASSEE	2700	2.50	6750	0.90	2420	0.45	1220	25	22	10850	90	3920	10	40	55	110	220	197	394
19	HIWASSEE	950	2.60	2460	1.00	950	0.50	475	143	135	7500	60	2580	15	20	28	56	112		
20	HIWASSEE	1050	2.60	2740	1.00	1050	0.50	525	110	100	2700	71	3060	10	30	41	82	162	28	56
22	HIWASSEE	1080	2.60	2810	1.00	1080	0.50	540	50	360	800	13	570	50	13	18	36	92	70	140

* PROJECTS INVOLVE 2 DEVELOPMENTS WITH FLUME LINES † PROJECTS 4 AND 21 ARE ALTERNATIVE

ATER POWERS OF TENNESSEE

RAGE							POWER AT 80% EFFICIENCY						
HARGE ONS PER ECOND RVICE	UPPER STORAGE DISCHARGE CU FEET PER SECOND FOR 24 HOUR SERVICE			TOTAL STORAGE DISCHARGE AT DAM CU. FEET PER SECOND FOR 24 HOUR SERVICE			ECONOMIC PLANT CAPACITY FOR ELECTRO-CHEMICAL UTILIZATION		ECONOMIC PLANT CAPACITY FOR DIVERSIFIED UTILIZATION		DISTANCE TO KNOXVILLE MILES	NAME OF RIVER	DAM NUMBER
3 MONTHS	1 YEAR	6 MONTHS	3 MONTHS	1 YEAR	6 MONTHS	3 MONTHS	HORSE POWER NOT UTILIZING UPPER STORAGE	HORSE POWER UTILIZING UPPER STORAGE	HORSE POWER NOT UTILIZING UPPER STORAGE	HORSE POWER UTILIZING UPPER STORAGE			
19	20	21	22	23	24	25	26	27	28	29	30	31	32
2620	——	——	——	655	1310	2620	16500	16500	25000	25000	38	POWELL	1
4400	——	——	——	1100	2200	4400	31000	31000	47000	47000	35	CLINCH	2
3840	2770	5540	11080	3730	7460	14920	74000	87000	110000	131000	20	CLINCH	3
48	4000	8000	16000	4012	8024	16048	19000	31000	28500	47000	33	CLINCH	4 †
1.00	4000	8000	16000	4275	8550	17100	34000	48500	51000	73000	33	CLINCH	21 †
1100	——	——	——	275	550	1100	37000	37000	56000	56000	41	HOLSTON	5
880	275	550	1100	495	990	1980	32000	45000	48000	68000	18	HOLSTON	6
544	1290	2580	5160	1425	2850	5700	30000	48000	45000	72000	0	TENNESSEE	7
36	——	——	——	9	18	36	9600	9600	14400	14400	86	NOLICHUCKY	8
1368	9	18	36	351	702	1404	13800	13800	20800	20800	46	NOLICHUCKY	9
384	351	702	1404	447	894	1788	11000	14000	16500	21000	38	NOLICHUCKY	10
440	942	884	3268	1052	2104	4208	34000	50000	51000	75000	28	FRENCH BROAD	11
440	1052	2104	4208	1162	2324	4648	20000	32000	30000	48000	16	FRENCH BROAD	12
544	——	——	——	136	272	544	72300	72300	10800	108000	45	PIGEON	13
180	——	——	——	45	90	180	9900	9900	14800	14800	26	ABRAM CREEK	14
164	3000	6000	12000	3041	6082	12164	8000	13500	12000	20000	27	LITTLE TENN.	15
——	——	——	——	——	——	——	2750	2750	4100	4100	46	TELLICO	16
440	87	174	348	197	394	788	10000	11000	15000	16500	70	HIWASSEE	17
220	197	394	788	252	504	1008	6700	8000	10000	12000	68	HIWASSEE	18
112				28	56	112	15000	15000	22500	22500	59	HIWASSEE	19
162	28	56	112	70	140	280	12400	13600	18600	20400	57	HIWASSEE	20
72	70	140	280	88	176	352	46000	55000	69000	82000	54	HIWASSEE	22

and the Holston, consideration is given to the fact that the rainfall on their respective drainage basins is less than that on the basins of the Hiwassee, Little Tennessee, etc., by from 10 to 15 percent.

Returning to the consideration of Table VII, column 10 shows the height of the proposed dams of each project, and column 11 the mean head under which each plant would operate. Some of the projects involve the building of flume lines, and in these cases heads of considerable magnitude become available.

Column 12 shows the area of the pool to be created by each dam. This area was determined by the process of drawing the flow-line upon the topographic map, interpolating the contour defined by the elevation of the crest of the dam, and then of measuring the area thus enclosed by the planimeter. Inasmuch as the contour interval on the topographic sheets is 100 feet, these figures are necessarily only approximate.

Storage capacity, columns 13 and 14, is calculated upon the assumption that the body of stored water is in form an inverted pyramid, with area of base equal to the area of pool, and with apex at the heel of the dam. The height of the pyramid is therefore equal to the height of the dam; and as the volume of a pyramid is obtained by determining the product of its base area by one-third its altitude, the volume of stored water is obtained by multiplying the area of pool by one-third of the height of dam. The result thus reached is of course very approximate, but is likely to be too small, rather than too large.

The assumed draw-down, in feet, column 15, is the distance below the crest of dam to which it has been supposed in each instance the water will be drawn in utilizing the storage; and column 16 is the volume of water occupying the space in the reservoir above the draw-down plane. The storage discharges then (columns 17, 18 and 19) are the conversion of the assumed draw-down (in acre-feet) into flow in cubic feet per second for 24 hours per day, for periods respectively of 12 months, 6 months and 3 months. Two acre-feet per day will yield a flow of one second-foot for 24 hours. One thousand acre-feet of storage would then yield 500 second-feet for one day, or 50 second-feet for ten days, or 1.37 second-feet for 365 days of 24 hours each.

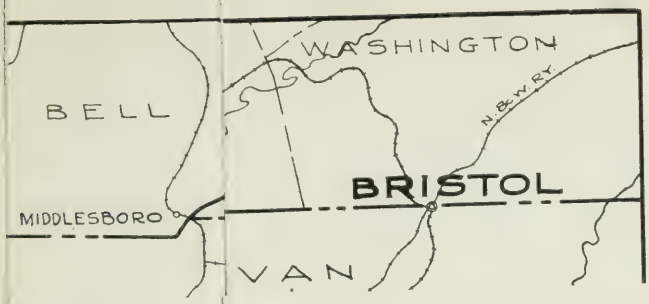
In columns 20, 21 and 22 is shown the additional storage discharge to be expected at a power site located lower on the river,

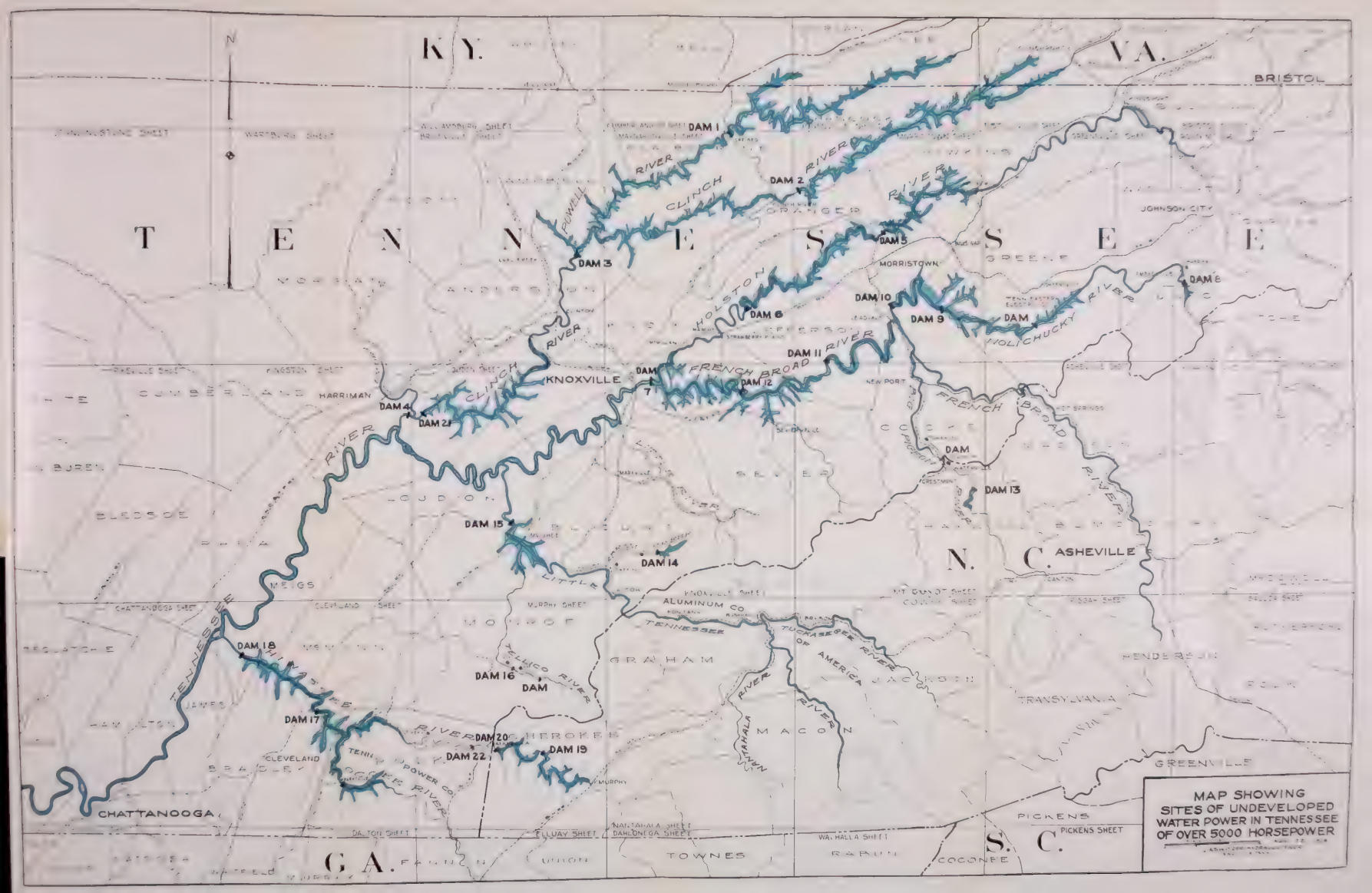
or on another river, from the upper reservoirs contemplated in the complete scheme of power development presented in this paper. And columns 23, 24 and 25 present the total flow to be expected from the complete storage, expressed in cubic feet per second for 24-hour flow for periods respectively of 12 months, 6 months and 3 months' duration.

Columns 26, 27, 28 and 29 are economic plant capacities, these being figured as already explained. One cannot give these figures serious study without becoming deeply impressed with the tremendous importance of the water powers of the western slopes of the Appalachian Mountains. Here lies a domain of wealth, yet undeveloped and awaiting, for its utilization, only a due appreciation of the possibilities which it contains.

Here, within a radius of eighty miles of this hall in which you gentlemen are sitting tonight are undeveloped water powers aggregating in round numbers 800,000 horsepower as figured for electrochemical utilization; within fifty miles nearly 700,000 horsepower. The rivers upon which they are located all flow through the valley of eastern Tennessee, and the power sites are all located within the same valley. And in the center of this region is situated the already thriving city of Knoxville, whose honored guests you are today. The region round about you is, too, bountifully endowed with many raw materials and advantages for chemical and metallurgical industries. Besides the water powers, Nature has provided here raw materials in barytes, clays, coal, copper, feldspar, iron, lead, limestone, lumber, manganese, marble, petroleum, phosphate, slate, sulphuric acid, tripoli and zinc. That this district is destined to become a most important industrial center can scarcely be doubted. The strategically central location of the territory makes this a logical district for economical production and distribution not only to the markets of the United States, but to the export markets as well. With congestion of our eastern ports becoming daily more acute, relief for the future must logically be sought through the utilization of the more southern ports; and to these, the Knoxville district has easy access.

May we not hope, gentlemen, that many of you will soon return, and bringing with you your skill, your energy, your capital and your enthusiasm, will join with us in bringing to fruition the unbounded development which is our heritage?


WASHINGTON
BELL
N.&W.RY.
BRISTOL
MIDDLESBORO
VAN


KY.
VA.
BRISTOL
TENNESSEE
N. C.
S. C.
GA.
ASHEVILLE
KNOXVILLE
CHATTANOOGA
JOHNSON CITY
MORRISTOWN
HARRIMAN
CLEVELAND
DAM 1
DAM 2
DAM 3
DAM 4
DAM 5
DAM 6
DAM 7
DAM 8
DAM 9
DAM 10
DAM 11
DAM 12
DAM 13
DAM 14
DAM 15
DAM 16
DAM 17
DAM 18
DAM 19
DAM 20
DAM 21
DAM 22
CLINCH RIVER
POWELL RIVER
HOLSTON RIVER
FRENCH BROAD RIVER
NOLICHUCKY RIVER
LITTLE TENNESSEE RIVER
TUCKASEGEE RIVER
OCONEE RIVER
ALUMINUM CO
TENN. POWER CO
MAP SHOWING
SITES OF UNDEVELOPED
WATER POWER IN TENNESSEE
OF OVER 5000 HORSEPOWER

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